PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION

VOL. 23, NO. 11 ▽ JANUARY-FEBRUARY-MARCH 1944

A CONTINUOUS CONCRETE BRIDGE

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - See page 2 of cover for prices

PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

Issued by the

FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION

Volume 23, No. 11 January–February–March 1944

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

In This Issue

	Page
Computing Moments for Continuous Concrete Bridges	273
The Effect of Tar, Ammonium Fluosilicate, and Sodium Hydroxide on the Alkali Resistance of Concrete	282
Determination of Cement Content of Soil-Cement Mixtures	297

THE PUBLIC ROADS ADMINISTRATION - Federal Works Agency Building, Washington 25, D. C.
REGIONAL HEADQUARTERS - - - - - - - - - - - - - - - - 720 Phelan Building, San Francisco 2, Calif.

▼

DISTRICT OFFICES

DISTRICT No. 1. Oregon, Washington, and Montana.
Post Office Building, Portland 8, Oreg.

DISTRICT No. 2. California, Arizona, and Nevada.
720 Phelan Building, San Francisco 2, Calif.

DISTRICT No. 3. Colorado, New Mexico, and Wyoming.
254 New Customhouse, Denver 2, Colo.

DISTRICT No. 4. Minnesota, North Dakota, South Dakota, and Wisconsin.
1109 Main Post Office Building, St. Paul, Minn.

DISTRICT No. 5. Iowa, Kansas, Missouri, and Nebraska.
729 U. S. Courthouse, Kansas City 6, Mo.

DISTRICT No. 6. Arkansas, Louisiana, Oklahoma, and Texas.
Room 502, United States Courthouse, Fort Worth 2, Tex.

DISTRICT No. 7. Illinois, Indiana, Kentucky, and Michigan.
2938 E. 92d St., Chicago 17, Ill.

DISTRICT No. 8. Alabama, Georgia, Florida, Mississippi, and Tennessee.
Post Office Building, Montgomery, Ala.

DISTRICT No. 9. Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.
76 State St., Albany 1, N. Y.

DISTRICT No. 10. Delaware, Maryland, Ohio, Pennsylvania, and District of Columbia.
Federal Works Agency Building, Washington 25, D. C.

DISTRICT No. 11. Alaska.
Room 419, Federal and Territorial Building, Juneau, Alaska.

DISTRICT No. 12. Idaho and Utah.
Federal Building, Ogden, Utah.

DISTRICT No. 14. North Carolina, South Carolina, Virginia, and West Virginia.
Montgomery Building, Spartanburg, S. C.

ALASKA HIGHWAY DISTRICT.
39 S. LaSalle St., Room 620, Chicago 3, Illinois.

Because of the necessarily limited edition of this publication it is impossible to distribute it free to any person or institution other than State and county officials actually engaged in planning or constructing public highways, instructors in highway engineering, and periodicals upon an exchange basis. At the present time additions to the free mailing list can be made only as vacancies occur. Those desiring to obtain PUBLIC ROADS can do so by sending 35 cents per year (foreign subscription 50 cents), or 10 cents per single copy, to the Superintendent of Documents, United States Government Printing Office, Washington 25, D. C.

CERTIFICATE By direction of the Commissioner of Public Roads, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

COMPUTING MOMENTS FOR CONTINUOUS CONCRETE BRIDGES

A METHOD APPLICABLE TO THREE SYMMETRICAL SPANS SIMPLY SUPPORTED

Reported by A. L. GOOGINS, Highway Bridge Engineer, G. B. CANAGA, Highway Bridge Engineer, and D. P. BABCOCK, Highway Bridge Engineer

A WELL DESIGNED continuous bridge has a depth of section that varies closely with the bending moment requirements from a minimum at the center of spans to a maximum at the intermediate supports. Reduction in deck depth, particularly at midspan, gives the continuous bridge an important economic advantage and improves architectural appearance. Only single bearings are required at interior supports, materially reducing the width of piers below that required for simple spans.

The time and difficulties involved in the design of continuous bridges, with members of variable moment of inertia, have prevented some designers from adopting such a design where it was a logical choice.

Continuous bridges may be of several spans of varying length but the more common type has three symmetrical, simply-supported spans. The charts accompanying this article have been prepared to simplify the design of this type of bridge.[1]

PROCEDURE IN PLOTTING CURVES

The curves presented here are plotted for continuous slab bridges but may be used in designing continuous girder bridges by transforming the girder section into a slab section having equivalent moments of inertia and using the value of r as determined for the transformed slab.

The terms used in this article are as follows:

See figure 2.

hc = depth of transformed slab at center of span,
r = ratio of increased depth, of transformed slab, at interior supports to depth of slab at center of span,
l = length of end spans,
n = ratio of length of center span to length of end span.

See figure 3.

y = difference between depth of girder at center of span and depth of girder at interior supports,
$x = \frac{\text{span length}}{2}$.

See figures 8 and 9.

K = ratio of distance from left end of span to position of concentrated load on the span, to the length of span.

See figure 10.

t = thickness of slab,
h = depth of girder section,
b = width of girder flange,
b_1 = width of girder stem.

[1] The publication "Continuous Concrete Bridges" (second edition), published by the Portland Cement Association will be found very useful in designing continuous concrete bridges having more than three spans and in designing unsymmetrical bridges.

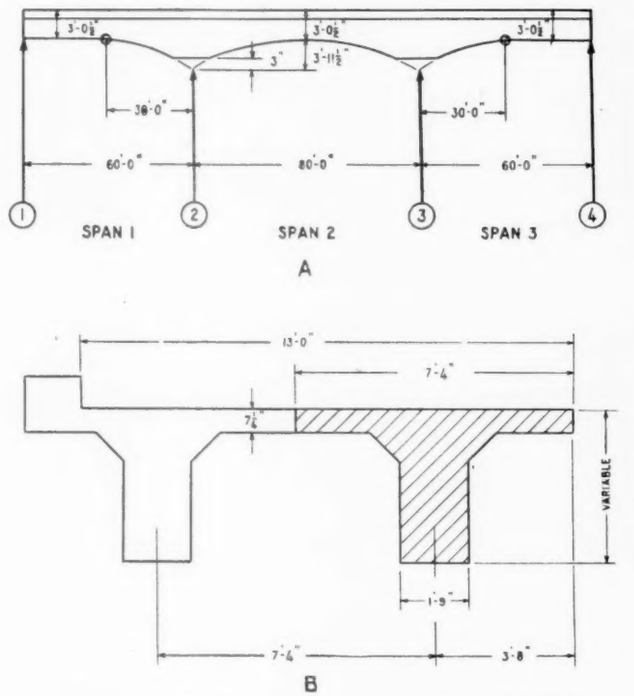


FIGURE 1.—GIRDER ELEVATION AND CROSS SECTION.

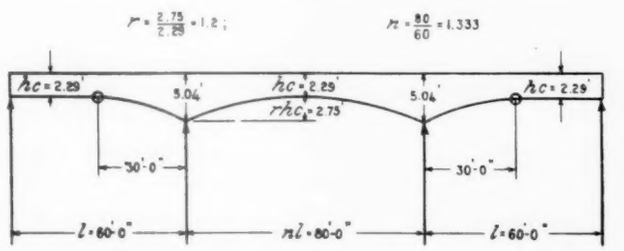


FIGURE 2.—DIMENSIONS OF SLAB AS DETERMINED FROM THE TRANSFORMED GIRDER.

The coefficient values used in plotting the curves of figures 5 to 9 were obtained by first determining the moments at the supports, by the distribution of fixed end moments.

When produced by a concentrated load these moments are influenced by the position of the load on the spans, by the length of the center span in relation to the length of the end span and by the relative thickness of the slab. These three variables, represented by K, n, and r require that two coefficients c and c_1 be used in expressing the moments in terms of Pl.

The moments at the supports in terms of Pl were first determined for various values of K and r when $n = 1.25$.

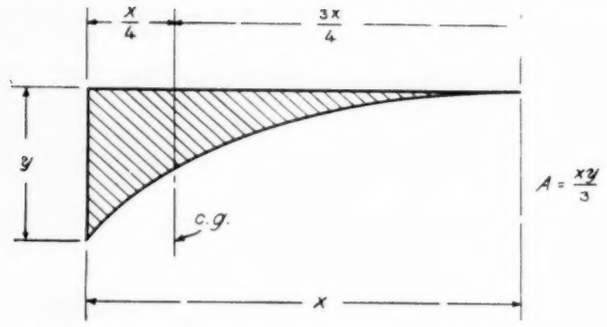


FIGURE 3.—COMPLEMENT OF HALF PARABOLA.

The moments thus determined were equated to cPl and the coefficients c determined. The moments at the supports in terms of Pl were then determined for other values of n, letting n vary from values of 1 to 2. The coefficients, c_1, express the moments for values of n other than 1.25 in percentage of the values as determined when $n=1.25$.

For a uniform load on any span fully loaded, the variable K does not exist, which permits the use of only one coefficient, c, in expressing the moments at the supports in terms of wl^2.

The stiffness factors, carry-over factors, and fixed end moments, necessary for the determination of the true moments at the supports by moment distribution, may be computed or taken from various tables prepared and published in connection with the subject of moment distribution. In this analysis the tables in the bulletin "Continuous Concrete Bridges" (second edition) published by the Portland Cement Association, were used.

If a continuous concrete slab is to be designed, it is first necessary to assume a depth of slab at the center of spans and a depth at the supports, from which the constants required in using the charts may be computed. Knowing the dead load of the assumed slab, the live load to be carried and the constants determined from the slab shape, it is possible to compute the moments and unit stresses for the assumed slab and revise the slab depth as the unit stresses indicate.

PROCEDURE IN DESIGNING A REINFORCED CONCRETE GIRDER BRIDGE

In designing a continuous reinforced concrete girder bridge, the width of roadway, the span arrangement, and the live load to be carried, will be known. It is necessary to assume the number, size, and spacing of the girders. The floor slab can then be designed and the loads to be carried by each of the trial girders determined. The next step is to transform the assumed girder into a slab shape having corresponding moments of inertia. With the structure constant, r, as determined for the transformed slab, together with the loads as computed for the assumed girder, the charts may be used to compute the girder moments. If the moments thus determined give unsatisfactory unit stresses, the girder shape must be changed and the process repeated until the desired unit stresses are obtained. Much work may be saved in determining trial sizes by using section 6 of "Continuous Concrete Bridges" published by the Portland Cement Association.

The example which follows is not a complete girder design, but is given to show the use of the charts in computing the moments, which when known, make stress determination a simple process.

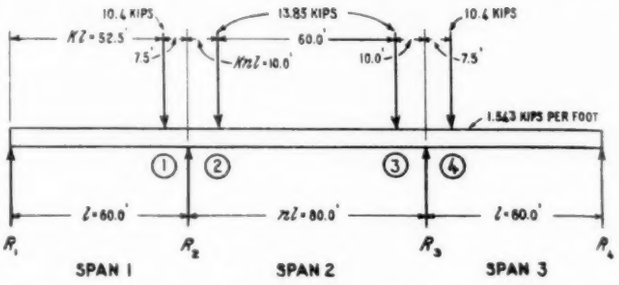


FIGURE 4.—AMOUNT AND POSITION OF GIRDER DEAD LOADS AS COMPUTED.

Assume three continuous spans as shown in figure 1. Transform the girder shown shaded in figure 1,B into a slab having equivalent moments of inertia.

The moments of inertia of the girder sections and for the equivalent slab sections are computed for the gross concrete sections without reinforcement.

Use figure 10 and compute moments of inertia for the girder at supports (2) and (3) figure 1 and at the center of the spans.

At supports:

$t=7\frac{1}{4}''$ (fig. 1, B),
$h=7'\ 0''$ (fig. 1, A),
$b=7'\ 4''$ (fig. 1, B),
$b_1=1'\ 9''$ (fig. 1, B).

$$\frac{t}{h}=\frac{0.604}{7.0}=0.0863$$

$$\frac{b_1}{b}=\frac{1.75}{7.33}=0.2387$$

In figure 10, the ordinate for $\frac{t}{h}=0.0863$, intersects the curve for $\frac{b_1}{b}=0.2387$ (visualized by interpolation) at $c=0.0312$. The moment of inertia, I, of the gross girder section at the supports, neglecting reinforcement, is $I=cbh^3=0.0312\times7.33\times7.0^3=78.4$ feet^4.

The depth at the supports for an equivalent slab section can then be computed by the formula $\frac{bd^3}{12}=78.4$ and solving for d. Here b, has the same value as before.

$$\frac{7.33d^3}{12}=78.4$$

$$d=\sqrt[3]{\frac{12\times78.4}{7.33}}=5.04 \text{ feet.}$$

At the center of spans:

$t=7\frac{1}{4}''$ (fig. 1, B),
$h=3'\ \frac{1}{2}''$ (fig. 1, A),
$b=7'\ 4''$ (fig. 1, B),
$b_1=1'\ 9''$ (fig. 1, B).

$$\frac{t}{h}=\frac{0.604}{3.04}=0.1988$$

$$\frac{b_1}{b}=\frac{1.75}{7.33}=0.2387$$

In figure 10 these values of $\frac{t}{h}$ and $\frac{b_1}{b}$ give the value $c=0.0354$. The moment of inertia, I, of the gross girder section at the center of the spans, neglecting reinforcement, is

$$I=cbh^3=0.0354\times7.33\times3.04^3=7.3 \text{ feet}^4$$

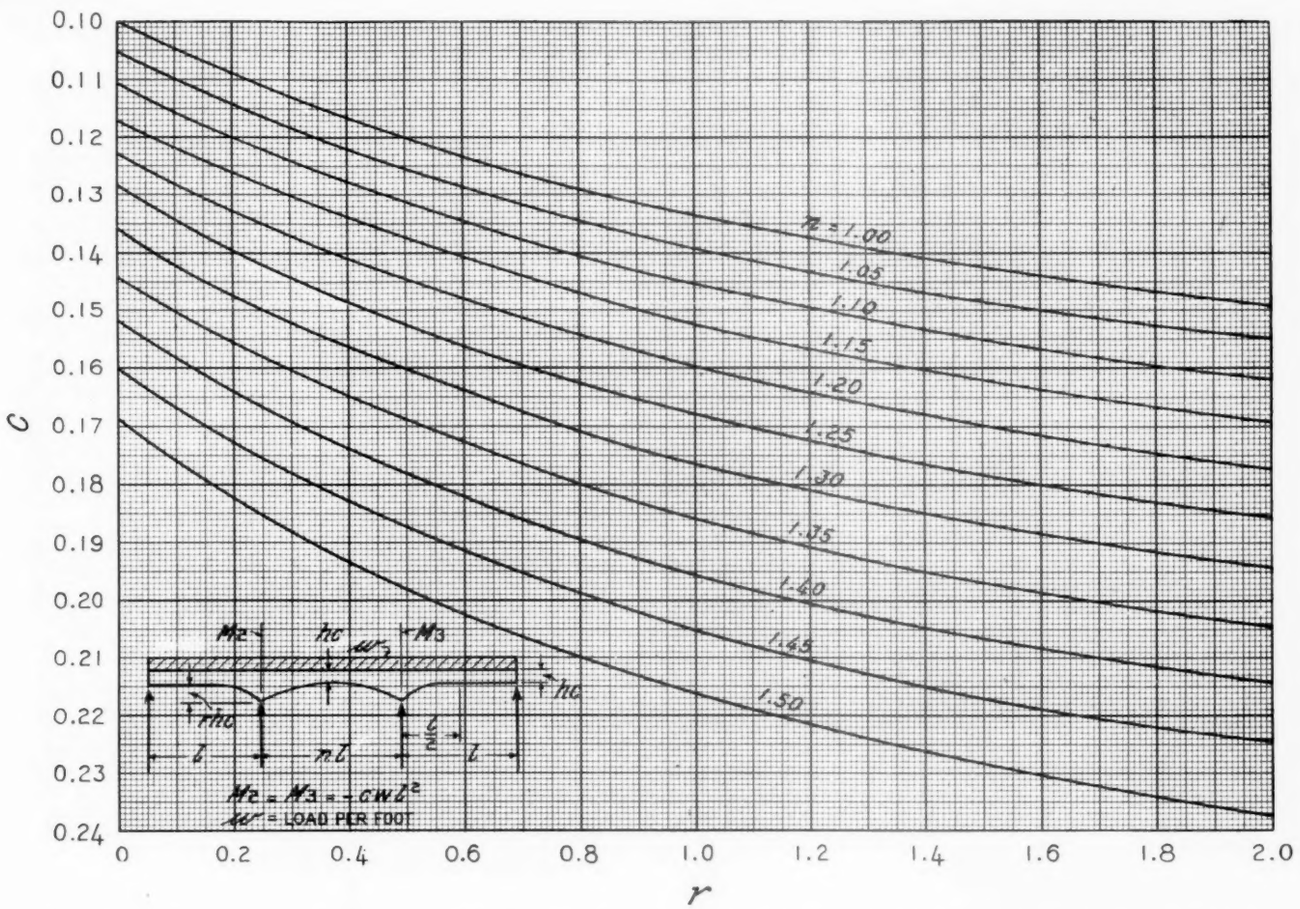


FIGURE 5.—DIAGRAM FOR DETERMINING MOMENTS AT INTERIOR SUPPORTS PRODUCED BY UNIFORM LOAD ON ALL SPANS.

The depth of an equivalent slab section, at the center of spans may now be computed:

$$\frac{bd^3}{12}=7.3$$

$$\frac{7.33d^3}{12}=7.3$$

$$d=\sqrt[3]{\frac{12\times7.3}{7.33}}=2.29 \text{ feet.}$$

Figure 2 shows the equivalent slab from which the values of r and n are determined.

For use in the solution with the charts $hc=2.29$; $rhc=5.04-2.29=2.75$; $r=\frac{2.75}{2.29}=1.2$; and $n=\frac{80}{60}=1.333$.

Compute the dead loads carried by the interior girder shown in figure 1, considering the weight of the curved portion of the girder stem as a concentrated dead load placed at the center of gravity of the complement of a half parabola. This may be done without changing the final solution appreciably, because the moments produced by the weight of the curved portion of the stem are very small in comparison to the total moments produced. The properties of the complement of a half parabola, are shown in figure 3. The remaining portion of the dead load is assumed uniform over all spans.

For dead loads considered as uniform:

7.33×0.604×0.15=0.664 kips, weight of slab,
1.75×2.436×0.15=0.640 kips, weight of girder stem,
0.5×0.75×0.15=0.056 kips, weight of girder fillets,
7.33×0.025=0.183 kips, future wearing surface,
1.543 kips, uniform dead load per foot of girder.

For dead loads considered as concentrated in the end spans:

$y=3.96$ feet, $x=30.0$ feet, $b_1=1.75$ feet.

$\frac{3.96\times30}{3}\times1.75\times0.15=10.4$ kips, weight of curved portion of stem (spans 1 and 3).

$\frac{30}{4}=7.5$ feet, distance of load from intermediate support (spans 1 and 3).

For dead loads considered as concentrated in the center span:

$y=3.96$ feet, $x=40.0$ feet; $\frac{3.96\times40}{3}\times 1.75\times0.15$,
$=13.85$ kips (span 2).

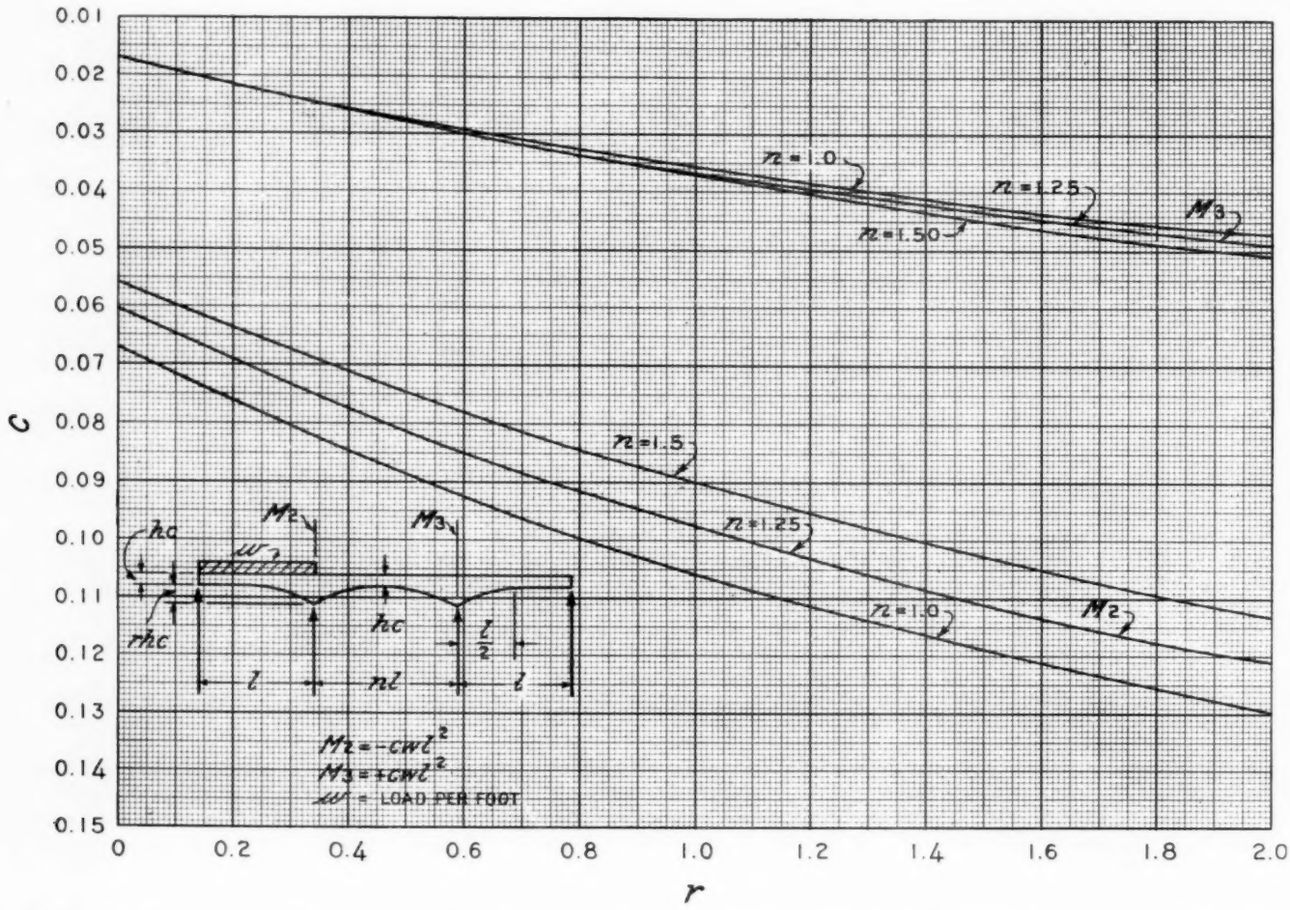


FIGURE 6.—DIAGRAM FOR DETERMINING MOMENTS AT INTERIOR SUPPORTS PRODUCED BY UNIFORM LOAD ON ONE END SPAN.

$\frac{40}{4}$=10.0 feet, distance of concentrated loads, in span 2, from supports.

Figure 4 shows the girder dead loads as computed above. The numbers in circles are for reference later in the example.

Consider that the bridge is to be designed for the equivalent H–20 live load as given by the Standard Specifications for Highway Bridges adopted by the American Association of State Highway Officials 1941. For this example we will use an impact factor of 0.27.

The lane width by the above specifications is to be 10 feet. Since the flange of the girder which we are considering is 7 feet, 4 inches wide, let it be assumed that the girder carries 0.733 of one lane load.

$0.733 \times 0.64 = 0.469$ kips per foot, uniform live load.

$0.733 \times 18.0 = 13.2$ kips, concentrated live load for moment.

In the determination of stress and the proper arrangement of reinforcing steel, it is necessary to know the moment and shears at many points. Much work can be saved, however, if in the preliminary calculations only the maximum negative moments at the supports and the maximum positive moments in the spans are determined.

COMPUTATION OF DEAD LOAD MOMENTS AT R_2

The positions of the dead loads are shown in figure 4.

Uniform dead load.—From figure 2, $r=1.2$, $n=1.333$, and from figure 5, $c=0.188$.

$M_2=-cwl^2=-0.188 \times 1.543 \times 60^2=-1044.3$ kip-feet

Concentrated dead loads.—For load (1)=10.4 kips, use figure 8. In addition to the values of n and r already determined from figure 2, a value of K, indicating the position of the load on the span, is required. (See fig. 4.)

$$K=\frac{52.5}{60}=0.875 \text{ for load (1).}$$

In figure 8 the ordinate for $K=0.875$ intersects the curve for $r=1.2$ (in group of curves for M_2) at a point $c=0.065$. Also from the small diagram at the lower right of figure 8 with $n=1.333$ and $r=1.2$ we obtain $c_1=0.975$. The moment at R_2 due to load (1) is then:

$M_2=-cc_1\ Pl=-0.065 \times 0.975 \times 10.4 \times 60=-39.5$ kip-feet.

For load (2) use figure 9.

$P=13.85$; $l=60.0$ feet; $K=0.125$; $r=1.2$; $n=1.333$

For moment at R_2, $c=0.0665$; $c_1=1.09$.

$M_2=-cc_1\ Pl=-0.0665 \times 1.09 \times 13.85 \times 60=-60.2$ kip-feet.

For load (3) use figure 9.

$$Knl=70 \text{ feet}; nl=80 \text{ feet}; K=\frac{70}{80}=0.875.$$

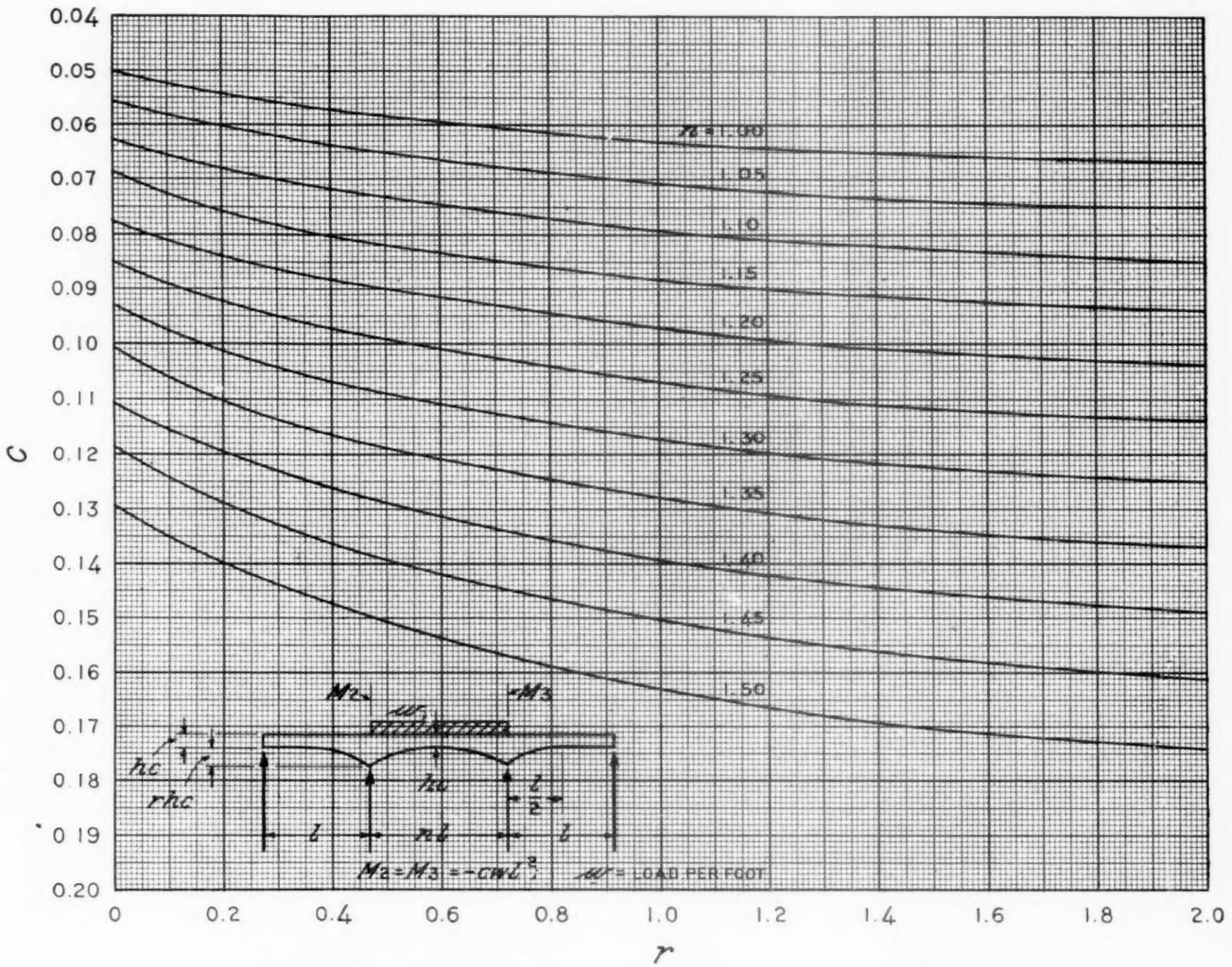


FIGURE 7.—DIAGRAM FOR DETERMINING MOMENTS AT INTERIOR SUPPORTS PRODUCED BY UNIFORM LOAD ON CENTER SPAN.

$P=13.85$ kips; $l=60$ feet; $r=1.2$; $n=1.333$

For moment at R_2, $c=0.0345$; $c_1=1.09$.

$M_2=-cc_1\ Pl=-0.0345\times 1.09\times 13.85\times 60=-31.3$ kip-feet

For load (4) use figure 8.

Since the spans are symmetrical the moment at R_2 caused by load (4) will be the same as the moment at R_3 due to load (1). From figure 8 compute M_3 due to load (1).

$K=0.875$; $r=1.2$; $n=1.333$; $P=10.4$ kips

$l=60$ feet; $c=0.0245$; $c_1=1.0$

$M_2=+cc_1\ Pl=+0.0245\times 1.0\times 10.4\times 60=+15.3$ kip-feet

Summary of dead load moments at R_2

−1,044.3 kip-feet, due to uniform, dead load
− 39.5 kip-feet, due to load (1),
− 60.2 kip-feet, due to load (2),
− 31.3 kip-feet, due to load (3),
+ 15.3 kip feet, due to load (4),

−1,160.0 kip-feet, total dead load moment at R_2.

Since the spans are symmetrical and the dead loads are symmetrically placed on the spans, the moments at R_2 and R_3 will be equal.

COMPUTATION OF LIVE LOAD MOMENTS AT R_2

Uniform live load.—The maximum negative moment at R_2 for the uniform live load occurs when spans 1 and 2 are fully loaded, with no load on span 3.

Use figure 6 to find the moment at R_2 due to the uniform live load on span 1.

$w=0.469$ kips per foot; $l=60$ feet

$r=1.2$; $n=1.333$; $c=0.101$

$M_2=-cwl^2=-0.101\times 0.469\times 60^2=-170.5$ kip-feet

Use figure 7 to find the moment at R_2 due to the uniform live load on span 2.

$w=0.469$; $l=60$; $r=1.2$; $n=1.333$

$c=0.128$.

$M_2=-0.128\times 0.469\times 60^2=-216.1$ kip-feet.

The moment at R_2 with both spans loaded is then $-170.5-216.1=-386.6$ kip-feet.

Concentrated live loads.—Figures 8 and 9 are used for finding moments due to concentrated loads.

Use figure 8 and compute M_2, when $P=13.2$; $r=1.2$; $n=1.333$.

$K=0.52$ (inspect chart and select value of K. corresponding to maximum moment).

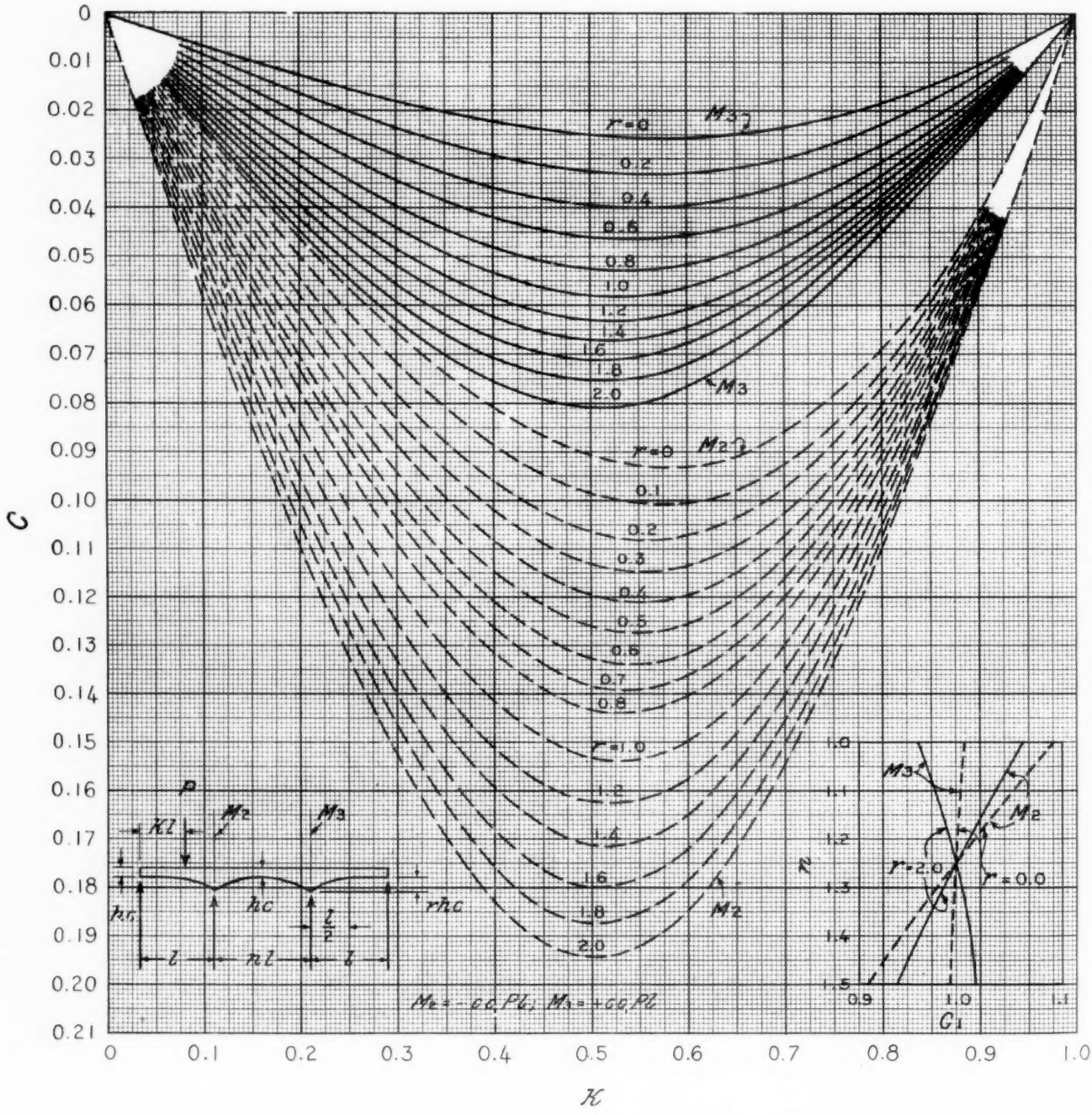


FIGURE 8.—DIAGRAM FOR DETERMINING MOMENTS AT INTERIOR SUPPORTS PRODUCED BY CONCENTRATED LOADS ON END SPAN.

$c=0.163$; $c_1=0.975$.

$M_2=-cc_1 Pl=-0.163\times0.975\times13.2\times60=-126.0$ kip-feet.

Use figure 9 and compute M_2, when $P=13.2$; $r=1.2$; $n=1.333$.

$K=0.41$; $c_1=1.09$; $c=0.148$.

$M_2=-cc_1 Pl=-0.148\times1.09\times13.2\times60=-127.7$ kip-feet.

As 127.7 is greater than 126.0, the concentrated load will be placed on span 2 as giving maximum moment at R_2.

Summary for maximum negative moment at R_2.

−1,160.0 kip-feet, dead load moment,
− 386.6 kip-feet, uniform live load moment,
− 127.7 kip-feet, concentrated live load moment,
− 138.9 kip-feet, impact (figured at 0.27),

−1,813.2 kip-feet, maximum negative moment at R_2.

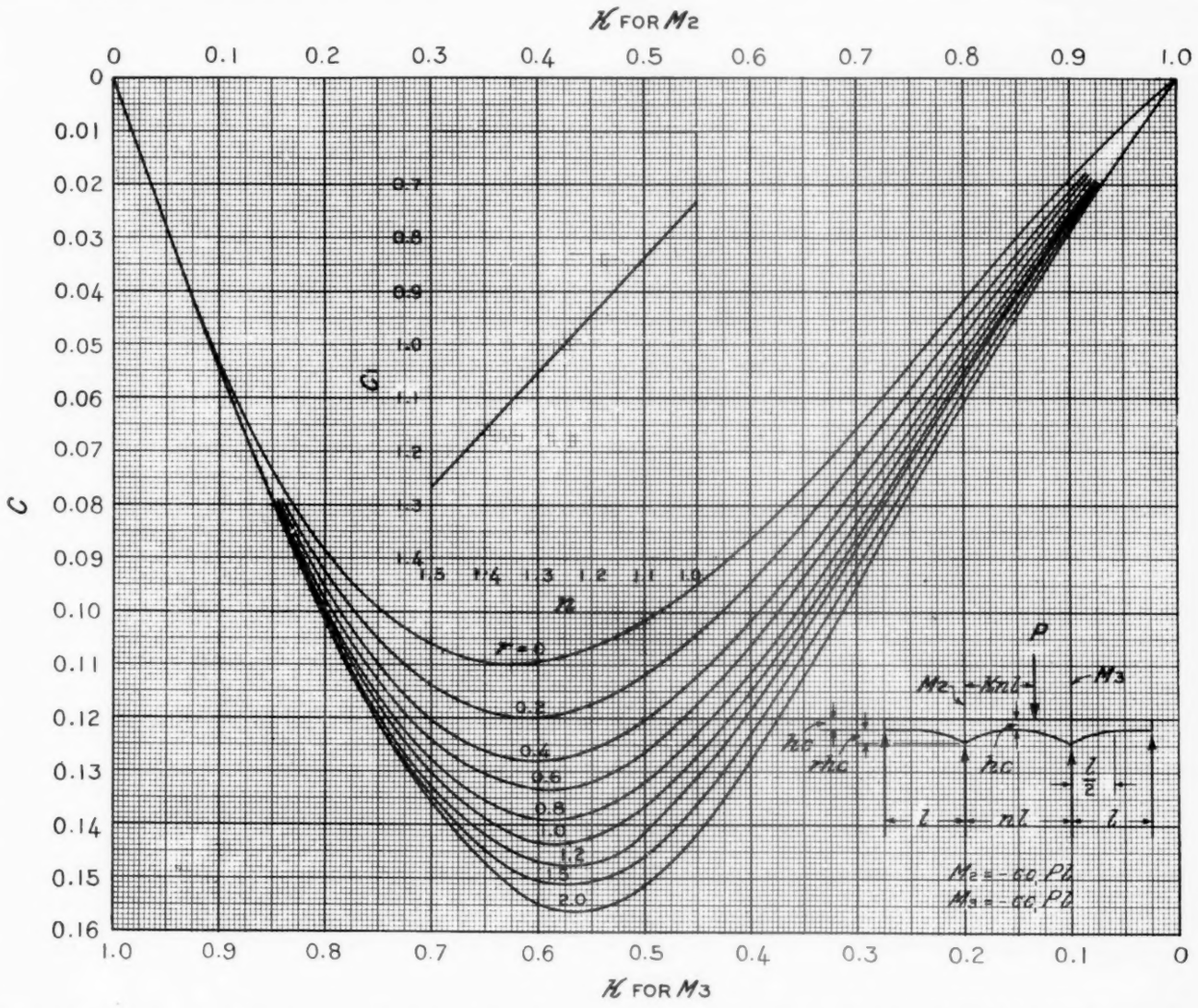


FIGURE 9.—DIAGRAM FOR DETERMINING MOMENTS AT THE INTERIOR SUPPORTS PRODUCED BY CONCENTRATED LOADS ON CENTER SPAN

MAXIMUM POSITIVE MOMENT IN SPAN 2

The maximum positive moment in span 2 will be at the center of the span when span 2 is fully loaded with uniform live load and when the concentrated live load is placed at the center of span.

Compute the dead load moment at the center of span 2. The dead load moments at R_2 and R_3 have previously been determined as −1,160.0 kip-feet.

$.125 \times 1.543 \times 80^2 = +1{,}234.4$ kip-feet,
$13.85 \times 10 = +\ 138.5$ kip-feet,

+1,372.9 kip-feet (simple span moment for dead load),
−1,160.0 kip-feet, dead load moments at R_2 and R_3
+ 212.9 kip-feet, dead load moment at center of span 2.

Compute the live load moment at the center of span 2 with uniform live load on span 2 only and with the concentrated load at the center of span. The moments at the supports are first to be determined from the charts and then the moment at the center is computed by statics.

The moment at R_2 or R_3 for the uniform live load on span 2 as previously determined is −216.1 kip-feet.

The moment at R_2 or R_3 for the concentrated live load at the center of span 2 may be determined from figure 9.

$K=0.5$, $n=1.333$, $r=1.2$, $P=13.2$, $c=0.141$, $c_1=1.09$.
$M_2=M_3=-cc_1Pl$
$M_2=M_3=-0.141\times1.09\times13.2\times60=-121.7$ kip-feet.

−216.1
−121.7

−337.8 kip-feet, live load moment at R_2 or R_3 with live load on span 2 in position for maximum positive moment in the span.

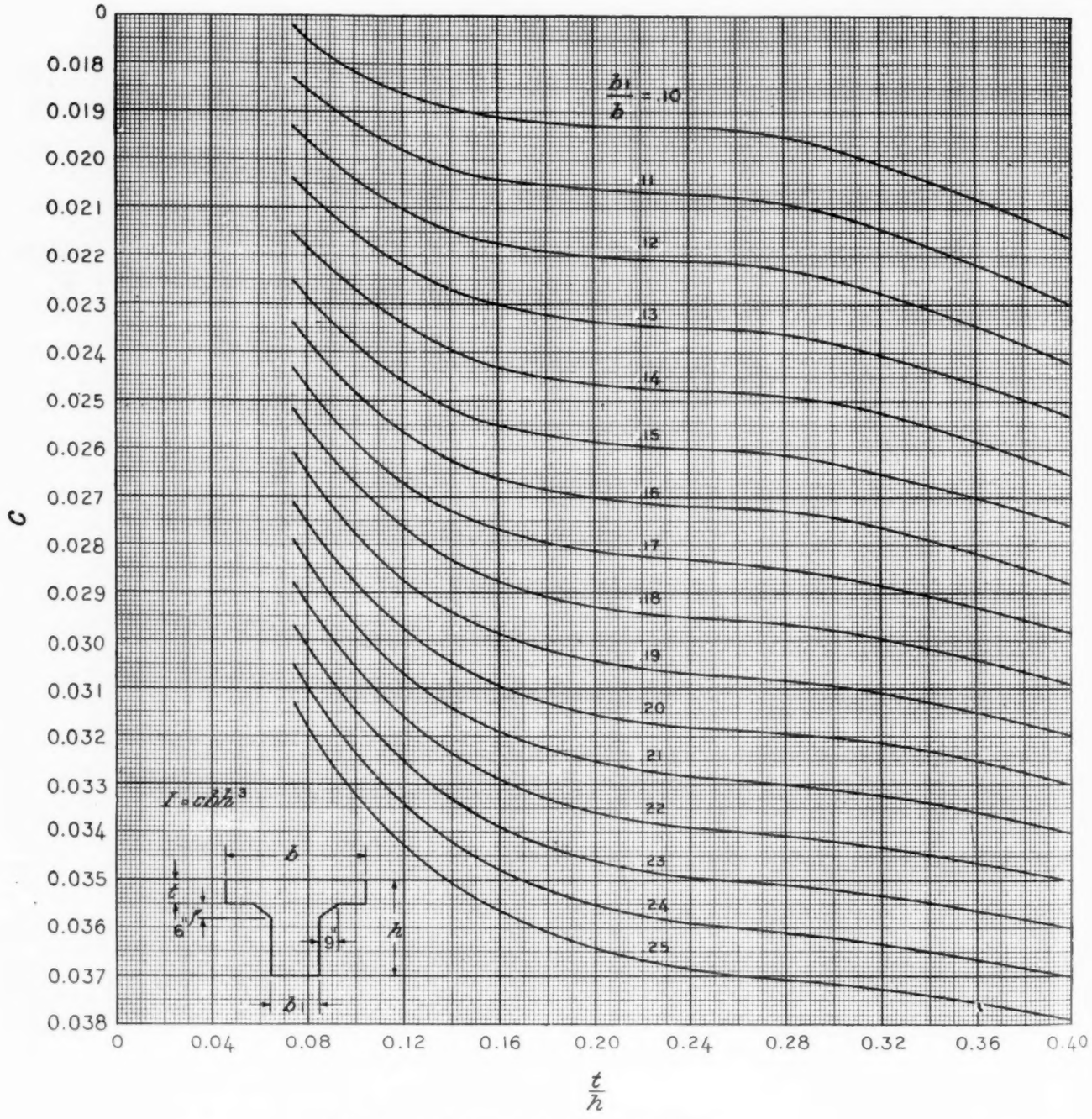


FIGURE 10.—MOMENTS OF INERTIA OF T-BEAMS

$0.125 \times 0.469 \times 80^2 = +375.2$ kip-feet,
$0.25 \times 13.2 \times 80 = +264.0$ kip-feet,

+639.2 kip-feet (simple span moment for live load),
−337.8 kip-feet, live load moment at R_2 and R_3,

+301.4 kip-feet, live load moment at center of span 2.

Summary of maximum positive moments in span 2.

+212. 9 kip-feet, dead-load moment,
+301. 4 kip-feet, live-load moment,
+81. 4 kip-feet, impact,

+595. 7 kip-feet, maximum positive moment at center of span 2.

MAXIMUM POSITIVE MOMENT IN END SPAN

The point of maximum positive moment in the end span is not apparent from an inspection of the figures or the girder layout, and is obtained by computing the moments for the various loads at sufficient points on

the span, so that these moments can be combined for the various points, and a maximum moment curve drawn. For the preliminary investigation to determine the size and shape of the girder, it will be sufficiently accurate to compute the moment at a point whose distance from the end support is 0.375 l.

$0.375 \times 60 = 22.5$ feet from end support

Dead-load moment.

$22.5 \times 37.5 \times 0.5 \times 1.543 = +650.9$

$\frac{10.4 \times 7.5 \times 22.5}{60} = +29.3$

$0.375 \times 1{,}160.0 = -435.0$

$+245.2$ kip-feet, dead load moment.

Live-load moment.—The maximum positive live-load moment at the point chosen will occur when the two end spans are loaded with uniform live load and when the concentrated live load is placed at the point.

Compute the moments at the supports for the uniform live load on the end spans.

The moment at R_2 for uniform live load on span 1 has previously been determined as -170.5 kip-feet. The moment M_2 for the uniform load on span 3 will be the same as the moment M_3 for the uniform load on span 1.

$w = 0.469$, $l = 60$, $r = 1.2$, $n = 1.333$, from figure 6, $c = 0.04$.

$M_3 = +0.04 \times 0.469 \times 60^2 = +67.6$ kip-feet.

$-170.5 + 67.6 = -102.9$ kip-feet, uniform live-load moment at R_2 or R_3 with both end spans loaded.

The uniform live-load moment at a point 22.5 feet from the end of the end spans will be:

$22.5 \times 37.5 \times 0.5 \times 0.469 = +197.8$

$-0.375 \times 102.9 = -38.6$

$+159.2$ kip-feet uniform live-load moment at 22.5 feet from end of end span.

Compute the moment at R_2 with the concentrated load at 22.5 feet from the end of the end span. Use figure 8.

$K = 0.375$, $l = 60$, $r = 1.2$, $n = 1.333$.

$P = 13.2$ kips. From figure 8, $c = 0.146$; $c_1 = 0.975$.

$M_2 = -0.146 \times 0.975 \times 13.2 \times 60 = -112.7$ kip-feet.

The concentrated live-load moment at a point 22.5 feet from the end of the end spans will then be:

$\frac{22.5 \times 37.5 \times 13.2}{60} = +185.5$ kip-feet,

$-0.375 \times 112.7 = -42.3$ kip-feet,

$+143.2$ kip-feet, concentrated live load moment at 22.5 feet from end of end span.

$+159.2$ kip-feet, uniform live load moment.

$+143.2$ kip-feet, concentrated live load moment,

$+302.4$ kip-feet, maximum positive live load moment at 22.5 feet from end of end span.

$0.27 \times 302.4 = 81.6$ kip-feet, allowance for impact for maximum positive moment in end span.

Summary of maximum positive moments for a point 22.5 feet from the end bearings.

$+245.2$ kip-feet, dead load moment,
$+302.4$ kip-feet, live load moment,
$+\ 81.6$ kip-feet, allowance for impact,

$+629.2$ kip-feet, total.

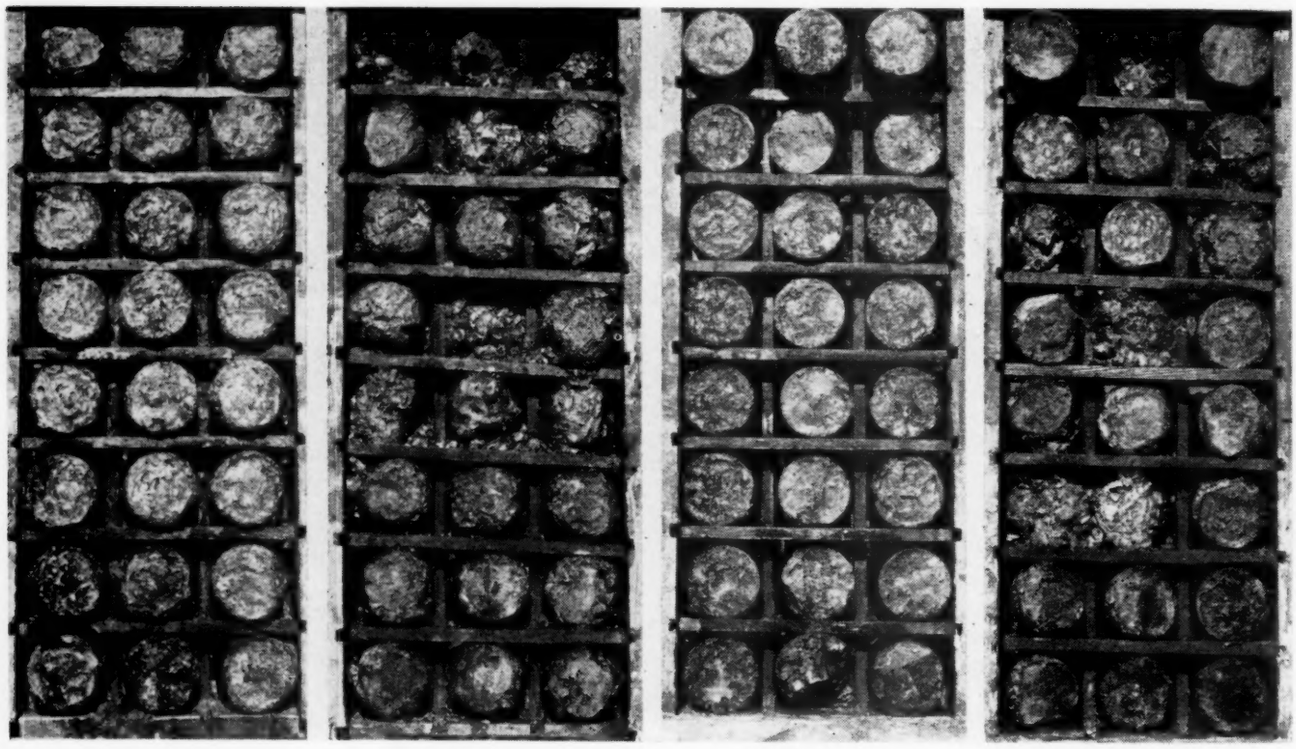
The maximum moments either positive, negative, or both, may be determined for any point, on the spans, as was done for the point 22.5 feet from the end bearings, by placing the loads on the spans in such a manner as to cause the maximum moment at the location desired.

567907—44——2

EFFECT OF TAR, AMMONIUM FLUOSILICATE, AND SODIUM HYDROXIDE ON THE ALKALI RESISTANCE OF CONCRETE

BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION

Reported by E. C. E. LORD, formerly Associate Petrographer, and D. G. RUNNER, Materials Engineer



Crate No.	142	143	144	145
Cure, moist	7 days	7 days	28 days	28 days
Cure, air	1 day	7 days	1 day	7 days

FIGURE 1.—CONDITION OF CONCRETE SPECIMENS WITH CEMENT A, AFTER 55 MONTHS IN MEDICINE LAKE. W/C RATIO=0.7. TWO TOP ROWS OF EACH CRATE IMMERSED ½ HOUR, WITH EACH SUCCESSIVE LOWER TWO ROWS IMMERSED 1 HOUR, 4 HOURS, AND 24 HOURS IN WATER-GAS TAR. DATA GIVEN IN TABLE 7.

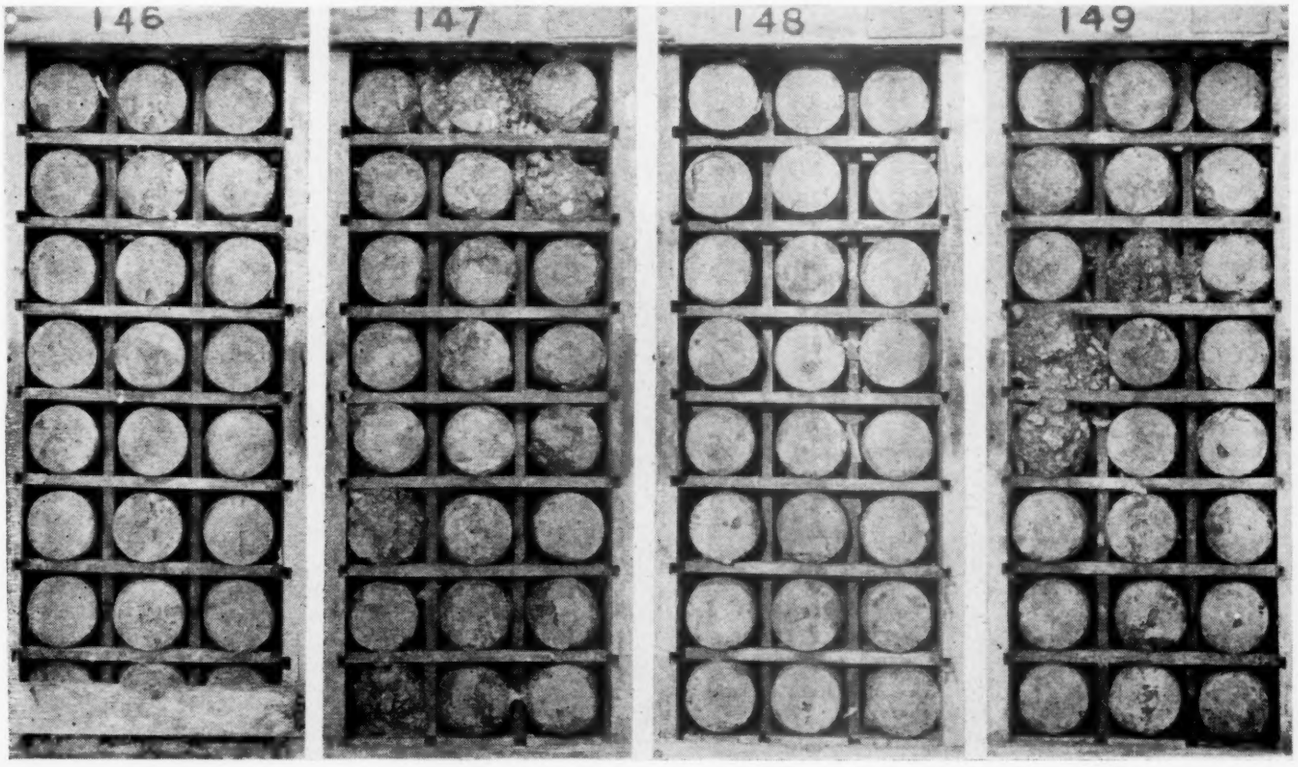
EARLY INVESTIGATIONS REVIEWED

For a number of years the Public Roads Administration has been conducting alkali-resistance tests on concrete surfaces treated with various protective materials such as water-gas tar, coal tar, paraffin, lubricating oil and linseed oil. The results on the earlier tests with water-gas tar, coal tar and paraffin have been reported in PUBLIC ROADS.[1] From the field and laboratory data, it was concluded that water-gas tar of proper quality is readily absorbed by cement mortar and concrete, the rate of absorption varying, however, with the manner of curing of the concrete, age, and density of the mix. Furthermore, it was concluded that four coats of water-gas tar applied at the rate of about one-fourth gallon per square yard of surface, followed by one coat of coal tar appears to afford adequate protection against alkali attack, provided the concrete is of good quality, has been properly fabricated and is not leaner than a 1 : 2 : 4 mix.

Results of subsequent investigations on alkali resistance using water-gas tar, coal tar, lubricating oil and linseed oil have also been published in PUBLIC ROADS.[2] From the test data relative to concrete protection, it was found that concrete of high cement content, cured for a limited period in air and treated with water-gas tar, is capable of offering appreciable resistance to alkali attack. It was observed that the protection against alkaline waters is influenced by the cement content, the method of curing and the consistency of the mix. Rich mixes of medium consistency cured for a minimum length of time in air gave best results.

[1] The Protection of Concrete Against Alkali, vol. 5, No. 3, May 1924; vol. 6, No. 11, January 1926; vol. 8, No. 6, August 1927.

[2] The Effect of Water-Gas Tar on the Strength and Alkali Resistance of Concrete, vol. 12, No. 4, June 1931.



Crate No.	146	147	148	149
Cure, moist	7 days	7 days	28 days	28 days
Cure, air	1 day	7 days	1 day	27 days

FIGURE 2.—CONDITION OF CONCRETE SPECIMENS WITH CEMENT A, AFTER 65 MONTHS IN MEDICINE LAKE. W/C RATIO=0.8. SAME PROTECTIVE TREATMENT AS GIVEN SPECIMENS IN FIGURE 1, PLUS ONE COAT OF COAL TAR. DATA GIVEN IN TABLE 8.

NEW SERIES OF TESTS DESCRIBED

In the investigations reported here, the tests were made on concrete specimens having water-cement ratios of 0.7 and 0.8 by volume. The aggregates were Potomac River sand having a fineness modulus of about 2.65 and Potomac River gravel containing 50 percent of ¾ to ½-inch size and 50 percent of ½-inch to No. 4 size.

Two brands of cement passing all the standard specification requirements were used in preparing the specimens. The results of physical and chemical tests on these cements are shown in table 1. The mix data and strength of the concrete are given in table 2. Comparing the chemical composition of the cements, it will be noted that while the major constituents (lime and silica) are about the same, the iron and alumina are present in widely different proportions. The concrete specimens made with cement B having a low alumina-iron ratio, as will be shown later, proved much more alkali resistant than those containing cement A with a high alumina-iron ratio.

The concrete specimens were 3- by 6-inch cylinders. For each water-cement ratio, curing conditions and protective treatment, a batch of three cylinders was cast for storage in sulphate solution in the laboratory and a batch of six cylinders was cast for storage in the waters of Medicine Lake, S. Dak.

For all methods of treatment the specimens were given an initial curing in the moist room of 7 days and 28 days, followed by curing in laboratory air. The periods of air curing were 1 and 7 days for the specimens to be treated with water-gas tar and 7 and 28 days for

TABLE 1.—*Properties of cement used in concrete specimens*

PHYSICAL PROPERTIES

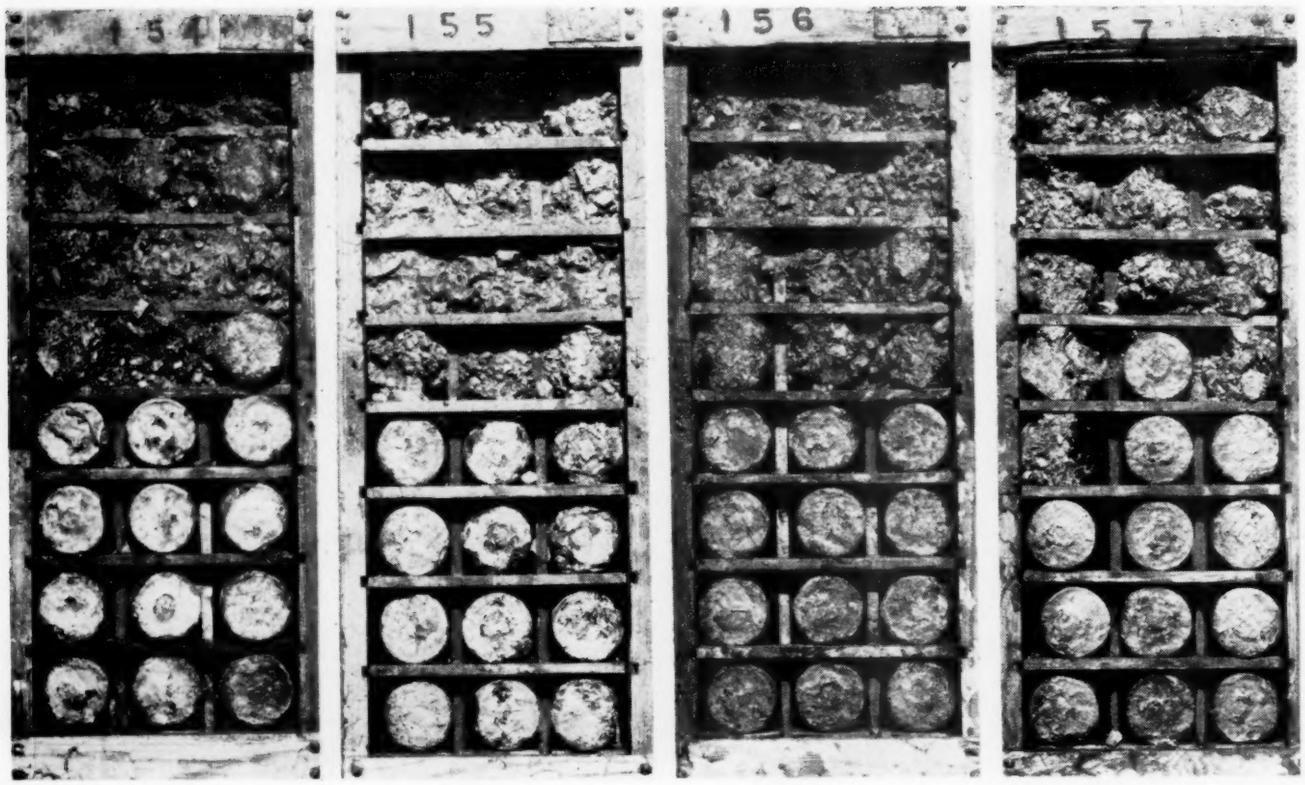
Item	Cement A	Cement B
Apparent specific gravity	3.14	----
Percentage retained on No. 200 sieve	13.9	8.5
Normal consistency, percent	23.0	23.6
Time of set, hours:		
Initial	2.3	5.5
Final	4.0	6.8
Tensile strength, lb. per sq. in.:		
7 days	325	335
28 days	385	390

CHEMICAL ANALYSES

Oxides	Percent	Percent
Silica (SiO_2)	21.25	20.50
Iron (Fe_2O_3)	2.84	8.04
Alumina (Al_2O_3)	6.16	4.76
Lime (CaO)	62.50	62.75
Magnesia (MgO)	2.96	0.92
Sulphuric anhydride (SO_3)	1.60	1.48
Loss on ignition	2.30	1.15
Ratio alumina to iron	2.17	.59

COMPUTED COMPOUND COMPOSITIONS

Compounds	Percent	Percent
Tricalcium silicate (C_3S)	43	62
Dicalcium silicate (C_2S)	31	12
Tricalcium aluminate (C_3A)	12	0
Tetracalcium alumino-ferrite (C_4AF)	9	23
Dicalcium ferrite (C_2F)	0	1
Calcium sulphate ($CaSO_4$)	2.7	2.5



Crate No.	154	155	156	157
Cure, moist	7 days	7 days	28 days	28 days
Cure, air	1 day	7 days	1 day	7 days

FIGURE 3.—CONDITION OF CONCRETE SPECIMENS WITH CEMENT A, AFTER 74 MONTHS IN MEDICINE LAKE. W/C RATIO=0.8. TWO TOP ROWS OF EACH CRATE GIVEN 4 COATS OF WATER-GAS TAR, THIRD AND FOURTH ROWS GIVEN 6 COATS OF WATER-GAS TAR. LOWER HALF OF CRATES GIVEN SAME TREATMENT AS UPPER HALF, PLUS ONE SEAL COAT OF COAL TAR. DATA GIVEN IN TABLES 9 AND 10.

TABLE 2.—*Mix data and compressive strength of concrete specimens*

W/C ratio by volume	Mix (dry rodded volume)	Cement factor	Slump	Flow
		Sacks per cubic yard	*Inches*	*Percent*
0.8	1:1.96:3.36	5.77	3½	185
0.7	1:1.70:2.90	6.57	3	185

COMPRESSIVE STRENGTH [1]

W/C ratio	Cured		Specimen containing cement A cured in air as indicated, followed by storage in moist air for—			Specimen containing cement B cured in air as indicated, followed by storage in moist air for—		
	Moist air	Laboratory air	9 days	30 days	365 days	9 days	30 days	365 days
	Days	*Days*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*
0.8	7	7	3,820	4,490	5,050	3,590	3,870	5,320
0.8	7	28	4,020	4,570	5,940	3,700	4,350	5,730
0.7	7	7	4,120	4,700	6,100	4,770	5,550	7,070
0.7	7	28	4,540	4,930	6,400	5,480	5,500	7,050

[1] Strength tests were made on batches of 3 cylinders, each stored in moist air for the periods indicated.

the specimens to be treated with ammonium fluosilicate and sodium hydroxide.

The protective materials used in these tests were water-gas tar, ammonium fluosilicate and sodium hydroxide, applied by immersion and by brush coating, followed in some cases by a seal coat of coal tar applied with a brush.

The tars were similar to those previously used, conforming to provisional specifications TW–1–X for water-gas tar and RTCB–5 for coal tar. The detail requirements for these materials are given in table 3.

TABLE 3.—*Requirements for water-gas tar and coal tar*

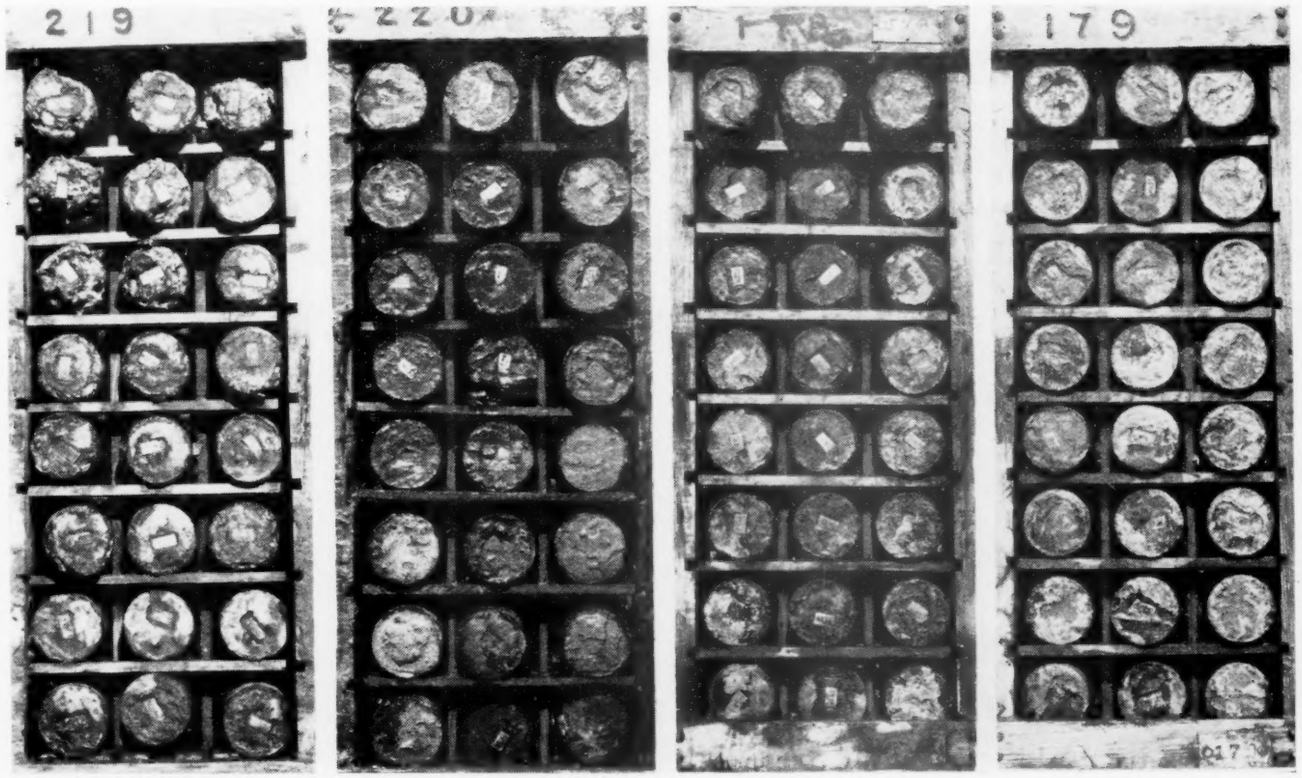
Grade	TW–1–X [1]	RTCB–5 [2]
1. Specific gravity, 25°/25° C. (77°/77° F.)	1.030–1.100	1.09+
2. *a.* Specific viscosity, 40° C	3.0–	
b. Specific viscosity, 50° C		17–26
3. Total distillate, percentage by weight:		
To 170° C		2.0–8.0
To 200° C		5.0+
To 235° C		8.0–18.0
To 300° C	50.0–	35.0–
a. Softening point of residue, ° C		40–70
4. Total bitumen, percentage by weight	98+	80+
5. Water, percentage by volume	3.0–	1.0–

[1] Water-gas tar for absorptive treatment shall be crude water-gas tar, which may be treated for removal of excess water if necessary to meet the detail requirements of the specification.

[2] Fluxed refined tar for seal application shall be prepared from refined gas house, coke-oven, and/or water-gas tars fluxed with suitable distillates.

Ammonium fluosilicate and sodium hydroxide were applied in solutions of 20 and 10 percent, respectively, by weight of the air-dried compounds.

As previously indicated, part of the specimens were stored in a sulphate solution in the laboratory and part of them were stored in the sulphate waters of Medicine Lake, S. Dak. The laboratory storage was in a solution containing 5 percent sodium sulphate and 5 percent magnesium sulphate. The waters of Medicine Lake



Crate No.	219	220	178	179
Cement	A	A	B	B
Cure, moist	7 days	7 days	7 days	7 days
Cure, air	7 days	28 days	7 days	28 days
Months in lake	37	37	62	61

FIGURE 4.—CONDITION OF CONCRETE SPECIMENS AFTER INDICATED NUMBER OF MONTHS IN LAKE. W/C RATIO=0.8. TWO TOP ROWS OF EACH CRATE IMMERSED ½ HOUR, WITH EACH SUCCESSIVE LOWER TWO ROWS IMMERSED 1 HOUR, 4 HOURS, AND 24 HOURS IN AMMONIUM FLUOSILICATE PLUS EQUIVALENT PERIODS OF IMMERSION IN WATER-GAS TAR. DATA GIVEN IN TABLES 11 AND 12.

contain high percentages of salts. Analyses made in 1923, 1924, and 1925 indicated a total salt content of from 2.34 to 4.72 percent, consisting almost entirely of a combination of magnesium and sodium sulphates in which the magnesium salt predominated.[3] A sample of water taken from the lake in July 1941 showed the following composition:

Magnesium sulphate	3.3 percent.
Sodium sulphate	1.4 percent.
Calcium sulphate	.3 percent.
Sodium chloride	.1 percent.
Calcium carbonate	.06 percent.
Specific gravity	1.0532

METHODS OF TREATMENT DESCRIBED

The protective treatments were applied to 16 major groups of specimens, each group containing 8 subgroups of either 2 or 4 batches of cylinders each. Batches for the laboratory storage contained 3 cylinders each and those for lake storage contained 6 cylinders each. The general schedule for the entire series is indicated in table 4. The major groups of specimens numbered 1 to 10, inclusive, were treated with water-gas tar and ammonium fluosilicate, and stored both in the laboratory and in Medicine Lake. The major groups numbered 5–S to 10–S, inclusive, constituted a supplementary series in which the primary treatment was with sodium hydroxide, the specimens being stored in the laboratory only.

[3] PUBLIC ROADS, vol. 6, No. 8, October 1925, p. 174.

Cement A was used throughout the entire investigation, while cement B was used only in the ammonium fluosilicate series.

In the earlier investigations it was found that the curing period was a factor in the absorption of the protective agents. In order to further investigate this effect, the concrete specimens were subjected to different periods of moist curing and air curing. After air curing, the protective treatments were applied.

The materials used in the initial treatments were water-gas tar, ammonium fluosilicate, and sodium hydroxide. These were applied both by immersion and by brush coating. For some specimens this was the final treatment. For other specimens the initial treatment was followed by a seal of coal tar consisting of one coat applied with a brush. Other specimens were given an initial treatment with ammonium fluosilicate or sodium hydroxide followed by an immersion or brush treatment with water-gas tar.

Immediately after air curing, the initial weights of the specimens were determined and they were then given the protective treatment. They were then weighed a second time to determine the absorption or retention of the protective liquid. After a period of drying and immediately before immersion in the sulphate solution, they were weighed again. This third weight was used in determining the change in weight that took place in the solution.

The specimens to be treated by immersion were weighed and immersed in the protective liquid for the

TABLE 4.—*Schedule of protective treatments*

Major group No.	Cement	Water-cement ratio	Curing		Protective material	Method of application	Period of immersion (hours)	Number of brush coats
			Moist	Air				
			Days	*Days*				
1	A	0.7 and 0.8	7 and 28	1 and 7	Water-gas tar	Immersion	½, 1, 4, and 24	
2	A	do	do	do	Water-gas tar followed by seal coat of coal tar	do	½, 1, 4, and 24	
						Brush coat		1.
3	A	do	do	do	Water-gas tar	do		4 and 6.
4	A	do	do	do	Water-gas tar followed by seal coat of coal tar	do		4 and 6.
						do		1.
5	A and B	do	do	7 and 28	Ammonium fluosilicate	Immersion	½, 1, 4, and 24	
6	A and B	do	do	do	Ammonium fluosilicate followed by seal coat of coal tar	do	½, 1, 4, and 24	
						Brush coat		1.
7	A and B	do	do	do	Ammonium fluosilicate followed by water-gas tar [1]	Immersion [1]	½, 1, 4, and 24	
8	A and B	do	do	do	Ammonium fluosilicate	Brush coat		4 and 6.
9	A and B	do	do	do	Ammonium fluosilicate followed by seal coat of coal tar	do		4 and 6.
						do		1.
10	A	do	do	do	Ammonium fluosilicate followed by water-gas tar	do		4 and 6.
						do		3.
10	B	do	do	do	Ammonium fluosilicate followed by water-gas tar	do		4 and 6.
						do		2.
5–S	A	do	do	do	Sodium hydroxide	Immersion	½, 1, 4, and 24	
6–S	A	do	do	do	Sodium hydroxide followed by seal coat of coal tar	do	½, 1, 4, and 24	
						Brush coat		1.
7–S	A	do	do	do	Sodium hydroxide followed by water-gas tar	Immersion [2]	½, 1, 4, and 24	
8–S	A	do	do	do	Sodium hydroxide	Brush coat		4 and 6.
9–S	A	do	do	do	Sodium hydroxide followed by seal coat of coal tar	do		4 and 6.
						do		1.
10–S	A	do	do	do	Sodium hydroxide followed by water-gas tar	do		4 and 6.
						do		4.

[1] The periods of immersion in water-gas tar and ammonium fluosilicate were the same. That is, specimens immersed for ½ hour, 1 hour, etc., in fluosilicate were then immersed for ½ hour, 1 hour, etc., respectively, in water-gas tar.
[2] The immersion procedure was the same as described in footnote 1 except that sodium hydroxide was used instead of ammonium fluosilicate.

TABLE 5.—*Effect of sulphate solution on untreated concrete stored in laboratory* [1]

CEMENT A

Series No.	Batch No.	W/C ratio	Cured—days		Percentage of gain in weight after laboratory storage																			
			Moist	Air	¼ month	5 months	7 months	8 months	9 months	10 months	12 months	20 months	21 months	31 months	32 months	33 months	43 months	44 months	45 months	68 months	69 months	91 to 93 months [2]	102 months	120 months
1	1	0.8	7	1	1.94				3.27	F														
	2		7	7	2.55					3.56	F													
	3		28	1	1.57				3.77	F														
	4		28	7	2.13				3.82	F														
2	5	.7	7	1	1.44					2.59	F													
	6		7	7	2.10					3.00	F													
	7		28	1	1.11				1.92	F														
	8		28	7	1.80				2.45	F														
3	9	.8	7	7	2.68	3.97		5.35	F															
	10		7	28	3.72	4.34		5.88	F															
	11		28	7	1.75	1.88		3.70	F															
	12		28	28	2.28	2.51		5.29	F															
4	13	.7	7	7	2.16	2.45		2.64			2.96	F												
	14		7	28	3.10	3.93		4.08			5.32	F												
	15		28	7	1.66	1.88		1.95			2.86	F												
	16		28	28	2.79	2.98		2.96			3.46	F												

CEMENT B

5	17	0.8	7	7	2.35				2.81				3.04			3.10			3.55		4.19	F (92)		
	18		7	28	3.48			3.76				4.19			4.36				5.04		5.80	F (92)		
	19		28	7	1.97				2.35			2.60			2.77				3.03		3.41	F (92)		
	20		28	28	2.85			3.36				3.55			3.76		4.57			4.95		F (92)		
6	21	.7	7	7	2.16				2.66				2.81			2.93			3.06		3.60	F (93)		
	22		7	28	3.08			3.33				3.33				3.64		3.73		5.34		F (92)		
	23		28	7	1.40		1.80					1.96		2.08			2.37			2.60		3.05 (91)	3.26	3.26
	24		28	28	1.66		2.28					2.51		2.63			2.90			3.27		3.92 (91)	4.04	4.04

[1] Specimens were tested in 6 series, each containing 4 batches of 3 cylinders to a batch. F indicates failure of specimens.
[2] Figures in parentheses indicate exact number of months in solution at time of weighing or number of months in solution until failure.

desired period of time. The periods were ½, 1, 4, and 24 hours. At the end of the immersion period the specimens were removed from the treating bath and allowed to drain for 1 hour before the second weight determination was made. If the specimens were to receive only this initial treatment, they were allowed to dry for 2 days, weighed for the third time, and immersed in the sulphate solution. In the case of groups 7 and 7–S, the initial immersion in ammonium fluosilicate or sodium hydroxide, was followed by immersion for equal periods of time in water-gas tar. After the first immersion, the specimens were allowed to dry before being immersed in the water-gas tar but otherwise the procedure was the same as for a single immersion.

The specimens for brush treatment were weighed and given 4 and 6 brush coats of the protective liquid, each coat being permitted to dry before the next coat was applied. After the final drying they were weighed and then, if no further treatment was intended, they were dried for an additional period of 2 days, weighed again,

and immersed in the sulphate solution. The same procedure was followed with the specimens of groups 10 and 10–S except that the initial brush treatments with ammonium fluosilicate and sodium hydroxide, respectively, were followed by brush treatments with water-gas tar.

The initial treatment of the specimens in groups 2, 4, 6, 9, 6–S, and 9–S was followed by a seal treatment of 1 brush coat of coal tar. These specimens were allowed to dry for 2 days after the initial treatment, the brush coat of coal tar was applied, and they were dried for an additional period of 2 days before being exposed to the alkali solution in the laboratory.

The specimens intended for storage in Medicine Lake were given the same treatments as those intended for laboratory storage. They were shipped in specially prepared crates containing 24 cylinders each, and were immediately placed in the lake, where they were inspected and photographed at yearly intervals at which time the condition of the specimens was recorded.

The laboratory specimens were placed in covered, porcelain-lined 5-gallon cans containing the sulphate solution.[4] After 7 days they were removed from the sulphate solution, dried for ½ hour in air and the gain in weight, based upon the dry weight after treatment, recorded. They were then transferred to paraffin-coated concrete storage tanks containing the sulphate solution and the gain in weight determined as before at intervals thereafter, or until failure.

In addition to the treated specimens that have been described, batches of cylinders without treatment were made for each brand of cement, water-cement ratio and method of curing for exposure to the sulphate solution. Immediately after the period of air curing they were immersed in the sulphate solution and weighed at intervals until failure. These specimens were allowed to remain in the original containers and were not transferred to the storage tanks.

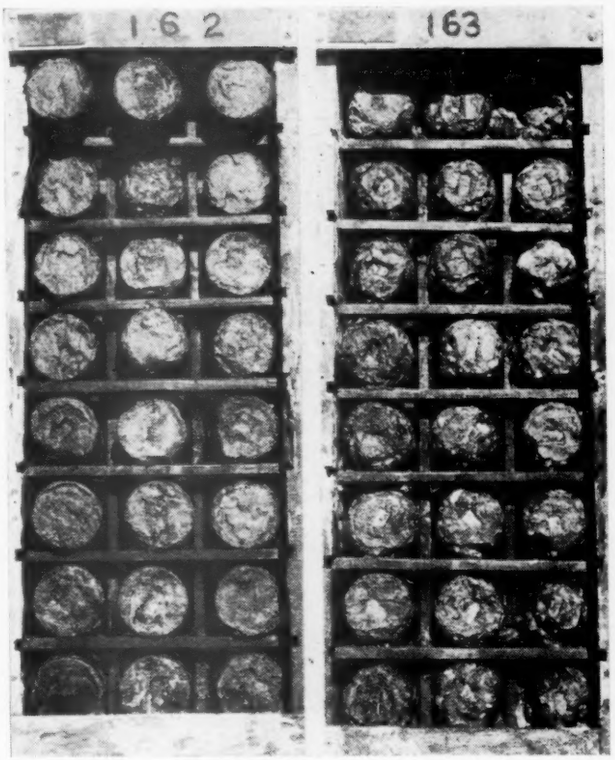
In all these laboratory tests, no attempt was made to maintain the initial concentration of the sulphate solution. The original volume of solution was maintained constant during the period of the tests by the addition of distilled water but no sulphates were added.

EFFECT OF ALKALI ON UNTREATED CONCRETE INVESTIGATED

Before discussing the protective effect of the compounds used in this investigation, it will be of interest to note the relative resistance to alkali attack offered by untreated concrete made with cement brands A and B. The results of these exposure tests are given in table 5.

It will be noted that three series containing cement A failed at 12 months or less, while one series failed at 20 months. On the other hand, all series containing cement B were intact at the end of 69 months. It appears that, for the curing conditions studied, the resistance to alkali attack, as measured by gain in weight, was increased as the period of moist curing was increased and as the period of air curing was decreased. This condition was noted for concrete of both 0.7 and 0.8 water-cement ratio. For comparable curing conditions the concrete having the lower water-cement ratio was the more resistant.

[4] This solution was made up in 5-gallon lots, each containing 2.25 pounds $MgSO_4 \cdot 7H_2O$ and 1 pound anhydrous Na_2SO_4.



Crate No.	162	163
Cure, moist	7 days	7 days
Cure, air	7 days	28 days
Months in lake	43	42

FIGURE 5.—CONDITION OF CONCRETE SPECIMENS WITH CEMENT B, AFTER NUMBER OF INDICATED MONTHS IN MEDICINE LAKE. W/C RATIO = 0.8. TWO TOP ROWS OF EACH CRATE IMMERSED ½ HOUR, WITH EACH SUCCESSIVE LOWER TWO ROWS IMMERSED 1 HOUR, 4 HOURS, AND 24 HOURS IN AMMONIUM FLUOSILICATE. DATA GIVEN IN TABLE 11.

PROTECTIVE VALUE OF WATER-GAS TAR, APPLIED BY IMMERSION, STUDIED

Exposure tests were made on concrete specimens containing low-alkali-resistant cement A treated with water-gas tar by immersion and by brush coats and both with and without seal coats of coal tar. The results of these tests on specimens stored in the laboratory and in Medicine Lake are given in tables 6, 7, 8, and 9, corresponding to major groups 1, 2, 3, and 4. The results of water-gas tar treatment by immersion alone are given in table 6.

It will be noted from the table that the average quantity of tar absorbed increased with the time of immersion, was greater in the concrete of 0.8 water-cement ratio than in that of 0.7 water-cement ratio, and was correspondingly greater in the specimens cured for 7 days in air than in those cured in air for 1 day. The average percentage of tar absorbed by samples having the same air curing was uniformly greater for the specimens moist cured for 7 days than for those moist cured for 28 days.

In regard to the protective effect of the tar treatment, the laboratory results indicate that the leaner mix (higher water-cement ratio), although more tar absorbent, was somewhat less sulphate resistant than the

TABLE 6.—*Protective effect of water-gas tar applied by immersion on concrete. Specimens stored in sulphate solution, major group 1, cement A* [1]

Subgroup No.	Crate No.	W/C ratio	Cured—days		Treatment, hours in water-gas tar	Percentage of water-gas tar absorbed	Percentage of gain in weight after laboratory storage				Number of lake samples attacked and failed after—					
			Moist	Air			¼ month	9 or 10 months	20 to 22 months [2]	22 to 33 months [2]	8 months	19 months	31 months	43 months	55 months	67 months
1	138	0.8	7	1	½	0.63	0.99	1.73	4.74 (21)	F (23)	0	0	6	6	F	
					1	.77	.91	1.40	4.25 (21)	F (23)	0	0	6	6	F	
					4	1.03	.57	1.01	4.28 (21)	F (33)	0	0	0	6	F	
					24	1.37	.44	.80	2.57 (21)	F (33)	0	0	0	6	F	
Average						.95	.73	1.23	3.96							
2	139	.8	7	7	½	1.03	1.37	2.29	F (21)		0	6	6	F		
					1	1.40	1.28	2.15	F (21)		0	6	6	F		
					4	1.82	.90	1.93	F (21)		0	0	6	F		
					24	2.34	.66	1.38	3.09 (21)	F (33)	0	0	6	6	F	
Average						1.65	1.05	1.94								
3	140	.8	28	1	½	.41	.94	1.75	F (22)		0	0	0	6	F	
					1	.51	.88	1.68	F (22)		0	0	0	6	F	
					4	.64	.60	1.09	4.74 (20)	F (27)	0	0	0	6	F	
					24	.82	.50	.81	2.93 (20)	F (27)	0	0	0	6	F	
Average						.60	.73	1.33								
4	141	.8	28	7	½	.67	1.45	2.42	9.23 (20)	F (22)	0	6	6	F		
					1	.82	1.18	1.94	6.33 (20)	F (22)	0	6	6	F		
					4	1.20	.90	1.49	3.90 (20)	F (27)	0	0	6	F		
					24	1.73	.58	1.10	2.38 (20)	F (27)	0	0	6	F		
Average						1.10	1.03	1.74	5.46							
5	142	.7	7	1	½	.64	.87	1.28	3.16 (21)	F (28)	0	6	6	6	6	F
					1	.73	.64	1.04	3.30 (21)	F (28)	0	0	6	6	6	F
					4	.97	.56	.90	2.73 (21)	F (31)	0	0	6	6	6	F
					24	1.15	.50	.75	2.25 (21)	F (31)	0	0	0	3	6	F
Average						.87	.64	.99	2.86							
6	143	.7	7	7	½	.63	1.22	1.70	5.46 (21)	F (22)	0	6	6	6	F	
					1	.90	1.02	1.48	4.73 (21)	F (22)	0	6	6	6	F	
					4	1.44	.84	1.18	3.82 (21)	F (27)	0	6	6	6	F	
					24	1.82	.64	.97	2.72 (21)	F (27)	0	0	6	6	F	
Average						1.20	.93	1.33	4.19							
7	144	.7	28	1	½	.33	.64	1.00	2.63 (20)	F (27)	0	0	0	6	6	F
					1	.41	.45	.89	2.08 (20)	F (27)	0	0	0	6	6	F
					4	.56	.43	.80	1.61 (20)	F (30)	0	0	0	6	6	F
					24	.66	.27	.58	1.52 (20)	F (30)	0	0	0	6	6	F
Average						.49	.45	.82	1.96							
8	145	.7	28	7	½	.59	1.08	1.64	1.98 (20)	F (31)	0	6	6	6	F	
					1	.68	.95	1.46	2.27 (20)	F (31)	0	6	6	6	F	
					4	1.08	.69	1.22	1.47 (20)	F (31)	0	6	6	6	F	
					24	1.51	.49	1.04	1.12 (20)	F (31)	0	0	6	6	F	
Average						.96	.80	1.34	1.71							

[1] Values based on 3 and 6 specimens for laboratory and lake storage, respectively. F indicates failure of specimens.
[2] Figures in parentheses indicate exact number of months in solution at time of weighing or number of months in solution until failure.

richer mix. It will be observed too that the quantity of sulphate absorbed by each subgroup of specimens, as indicated by the gain in weight, decreased as the time of immersion in the water-gas tar was increased. The greater resistance thus indicated was reflected to some extent in the ages at which failure took place, but the differences in age at failure are not sufficiently great to be considered of practical importance. After 33 months exposure to the sulphate solution all specimens stored in the laboratory had failed.

The effect of the water-gas tar treatment on the durability of samples stored in Medicine Lake showed approximately the same trend as that indicated by the laboratory specimens. However, all the lake specimens had failed at 67 months. Comparable subgroups of the richer mix were somewhat more alkali resistant than those of the leaner mix and the beneficial effect of the shorter air curing was also indicated. (See photographs in fig. 1, crates 142 to 145 inclusive.)

EFFECT OF WATER-GAS TAR WITH COAL TAR SEAL COAT

The results of the tests on concrete treated with water-gas tar by immersion, followed by a seal coat of coal tar, are given in table 7. A comparison of these results with those given in table 6 shows that the addition of the seal coat appreciably increased the resistance of the concrete to the action of sulphate waters.

Of the specimens shown in table 6, all had failed in the laboratory at 33 months. In contrast to this, table 7 shows that none of the seal-coated specimens failed in the laboratory until about 53 months and two of the subgroups were showing continued resistance at ages of 101 and 102 months.

The absorption of tar by the specimens shown in table 7 was affected by the different variables in the same manner as the specimens of table 6. Table 7 shows that the resistance of comparable subgroups of laboratory specimens was generally greater for the water-cement ratio of 0.7 (rich mix) than for the water-cement ratio of 0.8 (lean mix); and was greater for the specimens cured 1 day in air than for those cured 7 days in air.

With minor exceptions, the same factors that influenced the resistance of the laboratory specimens also influenced the resistance of the specimens stored in Medicine Lake. Insofar as the data for both laboratory and Lake specimens permit of a determination, it appears that little, if any, added durability is gained

TABLE 7.—*Protective effect of water-gas tar applied to concrete by immersion followed by a seal coat of coal tar. Specimens stored in sulphate solution, major group 2, cement A* [1]

Subgroup No.	Crate No.	W/C ratio	Cured—days: Moist	Cured—days: Air	Hours in water-gas tar	Percentage of tar absorbed: Water-gas tar	Percentage of tar absorbed: Coal tar	Percentage of gain in weight after laboratory storage—: ¼ month	⅞ or 8 months	41 or 42 months	53 or 54 months	65 or 66 months	77 or 78 months	101 or 102 month	113 months	Number of lake samples attacked and failed after—: 29 months	41 months	53 months	65 months	77 months	89 months	101 months	113 months	124 months
9	146	0.8	7	1	½	0.60	0.56	0.35	0.64	1.10	1.23	1.43	1.95	F		0	0	0	0	6	6	6	1F	3F
					1	.71	.62	.35	.60	1.10	1.29	1.54	2.01	F		0	0	0	0	0	0	3	3	1F
					4	.86	.62	.19	.46	.85	1.04	1.37	4.47	F		0	0	0	0	6	6	2F	3F	3F
					24	1.26	.62	.19	.40	.94	F					0	0	0	0	6	6	6	2F	2F
Average						.86	.61	.27	.53	1.00														
10	147	.8	7	7	½	.94	.41	.98	1.72	3.32	F					3	3	6	F					
					1	1.22	.44	.76	1.39	2.94	F					3	3	6	F					
					4	1.80	.49	.59	1.18	2.19	F					0	3	6	F					
					24	2.32	.39	.48	1.00	2.00	F					0	3	6	F					
Average						1.57	.43	.70	1.32	2.61														
11	148	.8	28	1	½	.46	.60	.48	.82	1.69	1.78	1.78	F			0	0	0	0	6	F			
					1	.59	.56	.48	.86	1.28	1.32	1.38	2.24	F		0	0	0	1	F				
					4	.75	.58	.37	.71	1.06	1.24	1.54	3.97	F		0	0	0	1	F				
					24	.85	.33	.29	.70	1.07	1.07	F				0	0	0	1	6	F			
Average						.66	.52	.40	.77	1.28	1.35													
12	149	.8	28	7	½	.53	.50	.54	1.42	3.26	F					0	0	3	6	6	F			
					1	.82	.48	.59	1.40	2.17	F					0	0	3	6	2F	F			
					4	1.19	.39	.21	.96	1.78	F					0	0	3	6	1F	3F	4F	F	
					24	1.83	.38	.04	.85	1.60	F					0	0	0	1	6	6	2F	F	
Average						1.09	.44	.35	1.16	2.20														
13	150	.7	7	1	½	.61	.44	.12	.71	1.21	1.42	1.67	2.79	F		0	0	1	2	6	6	6	6	6
					1	.61	.38	.02	.69	1.15	1.29	1.45	2.15	F		0	0	0	0	0	2	2	2	2
					4	.84	.40	0	.60	1.47	1.64	2.28	F			0	0	1	1	1	2	2	1F	2F
					24	1.04	.31	0	.56	1.12	1.16	1.41	3.22	F		0	0	1	2	6	6	6	1F	2F
Average						.77	.38	.04	.64	1.24	1.38	1.70												
14	151	.7	7	7	½	.68	.42	.50	1.20	1.75	1.88	1.92	2.13	F		0	0	0	1	6	6	6	4F	5F
					1	.95	.40	.38	1.11	1.57	1.76	1.76	2.10	2.81	F	0	0	0	0	1	1	2	4	1F
					4	1.34	.44	.27	.86	1.26	1.26	1.26	1.42	2.19	F	0	0	0	1	6	6	1F	1F	3F
					24	1.80	.44	.14	.76	1.14	1.14	1.14	2.96	F		0	0	0	1	6	6	3F	3F	4F
Average						1.19	.42	.32	.98	1.43	1.51	1.52	2.15											
15	152	.7	28	1	½	.39	.37	.23	.83	1.10	1.10	1.20	1.72	2.15	F	0	0	0	0	6	6	4F	F	
					1	.45	.39	.23	.84	.99	1.11	1.11	1.36	2.29	F	0	0	0	0	6	6	4F	F	
					4	.62	.41	.10	.64	.86	.94	.97	1.23	3.56	F	0	0	6	6	6	6	4F	F	
					24	.64	.43	.04	.60	.88	.94	.99	1.61	1.63	F	0	0	6	6	6	6	4F	F	
Average						.53	.40	.15	.73	.96	1.02	1.07	1.48	2.41										
16	153	.7	28	7	½	.40	.33	.44	1.42	2.15	F					0	0	0	0	6	6	1F	F	
					1	.57	.38	.27	1.26	2.61	F					0	0	0	1	6	6	1F	F	
					4	.91	.29	.15	1.07	1.80	F					0	0	0	1	6	6	2F	F	
					24	1.45	.28	.06	.97	2.11	F					0	0	3	2	F				
Average						.83	.32	.23	1.18	2.17														

[1] Values based on 3 and 6 specimens for laboratory and lake storage respectively. F indicates failure of specimens.

by increasing the period of immersion in water-gas tar beyond 1 hour. Photographs of crates 146 to 149, inclusive, are shown in figure 2.

PROTECTIVE VALUE OF WATER-GAS TAR APPLIED BY BRUSH COATING

The test results for concrete treated with water-gas tar applied by brush coating and for a comparable series of brush-coated specimens with a seal coat of coal tar are given in tables 8 and 9. The significant showing of these tables is the low protection afforded concrete by brush coats of water-gas tar (table 8) as compared to the protection given by the same treatment with an additional seal coat of coal tar (table 9). Over half of the entire lot of laboratory specimens with a brush coat only had failed at 40 months, while practically all the laboratory specimens with an additional seal coat were intact at 76 months. The test results indicate about the same general relations between water-cement ratio, method of curing and tar absorption as were recorded in tables 6 and 7 for the immersion treatment.

Comparing the effect of the treatments on specimens stored in Medicine Lake, it will be noted that nearly all cylinders treated with water-gas tar alone had failed after an exposure of 74 months or less (table 8), while of those receiving the coal tar seal coat, only two failures were recorded at 74 months (table 9). Photographs of crates 154 to 157 inclusive in figure 3 show the condition of four representative subgroups with and without seal coats of coal tar.

EFFECT OF AMMONIUM FLUOSILICATE ALONE AND IN COMBINATION WITH WATER-GAS TAR AND SEAL COATS OF COAL TAR

A preliminary investigation of various fluosilicate compounds indicated that the ammonium salt, when applied to concrete in a 20-percent water solution, was effective in retarding sulphate attack, especially when followed by an application of water-gas tar or coal tar. Exposure tests were therefore carried out on specimens

TABLE 8.—*Protective effect of water-gas tar applied to concrete by brush coating. Specimens stored in sulphate solution, major group 3, cement A* [1]

Subgroup No.	Crate No.	W/C ratio	Cured—days: Moist	Cured—days: Air	Brush coats of water-gas tar	Water-gas tar absorbed	Percentage of gain in weight after laboratory storage: ¼ month	4 to 6 months	15 to 17 months	23 to 29 months [2]	38 to 40 months	51 months	Number of lake samples attacked and failed after—: 14 months	26 months	38 months	50 months	62 months	74 months	86 months	98 months	110 months	121 months
17	154	0.8	7	1	4	0.86	0.68	1.31	1.90	F (29)			0	6	6	2F	F					
					6	1.12	.51	1.10	1.80	F (29)			0	6	6	1F	4F	F				
Average						.99	.59	1.20	1.85													
18	155	.8	7	7	4	.99	1.09	1.92	5.64	F (23)			6	6	F							
					6	1.44	.89	1.68	5.45	F (23)			6	6	F							
Average						1.22	.99	1.80	5.54													
19	156	.8	28	1	4	.73	.67	1.23	2.11	F (28)			0	6	F							
					6	.97	.55	1.09	1.74	F (28)			0	6	6	6	F					
Average						.85	.61	1.16	1.92													
20	157	.8	28	7	4	.59	1.19	1.96	2.40	F (27)			0	6	6	3F	F					
					6	.80	.84	1.72	2.16	F (27)			0	6	6	2F	F					
Average						.70	1.01	1.84	2.28													
21	158	.7	7	1	4	.85	.82	1.72	2.37	2.51 (28)	F		0	6	6	6	F					
					6	1.20	.53	1.24	2.26	2.58 (28)	F		0	6	6	6	6	6	F			
Average						1.03	.67	1.48	2.32	2.54												
22	159	.7	7	7	4	.95	.93	1.65	2.56	2.67 (28)	F		0	6	6	1F	F					
					6	1.33	.82	1.51	2.33	2.44 (28)	F		0	6	6	6	3F	F				
Average						1.14	.87	1.58	2.44	2.56												
23	160	.7	28	1	4	.40	.79	1.41	1.83	2.20 (29)	2.62	F	0	6	6	6	4F	F				
					6	.52	.56	1.11	1.24	1.56 (29)	1.79	F	0	6	6	6	2F	F				
Average						.46	.67	1.26	1.53	1.88	2.20											
24	161	.7	28	7	4	.46	.75	1.15	1.55	1.90 (27)	2.41	F	0	0	0	0	2	F				
					6	.57	.73	.99	1.56	1.98 (27)	2 11	F	0	0	0	0	2	2	4	1F	5F	F
Average						.52	.74	1.07	1.55	1.94	2.26											

[1] Values based on 3 and 6 specimens for laboratory and lake storage respectively. F indicates failure of specimens.
[2] Figures in parentheses indicate number of months specimens had been in solution at time of weighing, or number of months in solution until failure.

treated with this material alone and in combination with water-gas tar and seal coats of coal tar in the manner indicated in table 4. The concrete test specimens were fabricated both with low alkali-resisting cement A and with high alkali-resisting cement B.

As the exposure tests progressed, it became evident that the alkali resistance did not materially increase with the quantity of fluosilicate applied, but was affected more by the curing of the test samples. For this reason the results of individual treatments have been combined and the values recorded in tables 10 and 11 are the averages of all treatments applied to each subgroup of specimens.

The laboratory test results indicate that none of the treatments involving the application of ammonium fluosilicate to concrete made with cement A (table 10) was particularly effective.

The specimens of major group 5, treated with fluosilicate by immersion, showed no better resistance than similar untreated specimens (table 5) while, with the exception of major group 7, few of the laboratory specimens attained ages greater than 20 months. The lake specimens showed about the same general trend of performance as that for the laboratory specimens. Major group 7, treated by immersion with fluosilicate and water-gas tar, has shown the best resistance to sulphate action, both in the laboratory and in the lake, but even in this group the performance is not impressive as compared with that of the specimens treated with water-gas tar and given a seal coat of coal tar. (See tables 7 and 9.)

Table 11 shows the results obtained with the various treatments with ammonium fluosilicate and tar applied to concrete made with cement B. In view of the results shown in table 10 for concrete made with cement A, it must be concluded that the greatly superior resistance recorded in table 11 is due primarily to the character of the cement rather than to the protective treatments. It is also concluded that ammonium fluosilicate, either alone or in the various combinations with water-gas tar and coal tar, does not afford effective protection to concrete exposed to the action of sulphate waters.

Photographs of representative crates of specimens from major group 7, made with cements A and B, are shown in figure 4. Two crates from major group 5 made with cement B are shown in figure 5.

PROTECTIVE VALUE OF SODIUM HYDROXIDE

The specimens in major groups 5–S to 10–S, inclusive, were made with cement A and the treatments were identical with those given the specimens in the corresponding major groups 5 to 10, inclusive, except that a 10-percent solution of sodium hydroxide was substituted for the 20-percent solution of ammonium fluosilicate. The results of the exposure tests, which were made only in the laboratory, are shown in table 12.

TABLE 9.—*Protective effect of water-gas tar applied to concrete by brush coating, followed by a seal coat of coal tar. Specimens stored in sulphate solution, major group 4, cement A* [1]

Sub-group No.	Crate No.	W/C ratio	Cured—days: Moist	Cured—days: Air	Brush coats of water-gas tar	Percentage of tar absorbed: Water-gas tar	Percentage of tar absorbed: Coal tar	Percentage of gain in weight after laboratory storage: ¼ month	4 to 6 months	51 or 52 months	62 to 64 months	74 to 76 months	99 or 100 months	110 to 112 months	129 months	Number of lake samples attacked and failed after—: 14 months	26 months	38 months	50 months	62 months	74 months	86 months	98 months	110 months	121 months
25	154	0.8	7	1	4	0.86	0.30	0.32	0.87	1.31	1.71	1.82	2.85	F		0	0	0	0	2	6	F			
					6	1.11	.31	.19	.61	1.29	1.75	3.06	F			0	0	0	0	1	6	F			
Average						.99	.30	.26	.74	1.30	1.73	2.44													
26	155	.8	7	7	4	.99	.27	.46	1.10	3.82	F					0	0	3	3	3	2F	F			
					6	1.44	.27	.38	.98	2.12	2.82	4.20	F			0	0	0	1	1	6	F			
Average						1.22	.27	.42	1.04	2.97	4.07														
27	156	.8	28	1	4	.74	.30	.42	1.08	F						0	0	0	0	3	6	6	F		
					6	.97	.30	.25	.90	F						0	0	0	0	2	6	6	F		
Average						.85	.30	.33	.99																
28	157	.8	28	7	4	.59	.31	.67	1.56	2.54	3.00	3.79	4.69	F		0	0	0	0	1	6	1F	F		
					6	.80	.31	.55	1.32	2.00	2.18	2.29	4.51	F		0	0	0	0	1	6	6	F		
Average						.70	.31	.61	1.44	2.27	2.59	3.04	4.60												
29	158	.7	7	1	4	.86	.28	.23	.80	1.28	1.32	1.55	F			0	0	0	0	1	6	6	6	1F	2F
					6	1.20	.28	.13	.84	1.32	1.32	1.51	F			0	0	0	0	1	6	6	6	6	2F
Average						1.03	.28	.18	.82	1.30	1.32	1.53													
30	159	.7	7	7	4	.94	.34	.35	.88	1.42	1.44	1.56	1.93	2.04	2.04	0	0	0	0	2	6	6	6	3F	F
					6	1.33	.34	.25	.90	1.44	1.50	1.55	1.88	2.17	2.17	0	0	0	0	2	6	6	1F	1F	F
Average						1.14	.34	.30	.89	1.43	1.47	1.55	1.90	2.10	2.10										
31	160	.7	28	1	4	.40	.37	.31	.90	1.19	1.33	1.44	2.10	F		0	0	0	0	1	6	6	1F	F	
					6	.53	.37	.23	.80	1.08	1.27	1.35	1.89	2.37	3.28	0	0	0	0	1	6	6	2F	F	
Average						.46	.37	.27	.85	1.14	1.30	1.39	1.99												
32	161	.7	28	7	4	.46	.39	.59	.98	1.77	1.96	2.27	5.26	F		0	0	0	0	0	0	0	3	5	1F
					6	.57	.39	.33	.80	1.60	1.70	2.14	F			0	0	0	0	0	0	0	0	2	2F
Average						.52	.39	.46	.89	1.68	1.83	2.20													

[1] Values are based on 3 and 6 specimens for laboratory and lake storage respectively. F indicates failure of specimens.

The protection afforded by the treatments involving the use of sodium hydroxide was, with some exceptions, generally superior to that afforded by the similar treatments with ammonium fluosilicate. It is perhaps noteworthy that the greatest resistance to attack was shown by the specimens of major groups 6–S and 9–S which were the only ones with a seal coat of coal tar. However, the protection afforded by the sodium hydroxide treatments was distinctly inferior to the protective effect of the treatment with water-gas tar followed by a seal coat of coal tar as recorded in tables 7 and 9.

CONCLUSIONS

From the data that have been presented, the following conclusions are drawn:

1. The trends of performance of the specimens exposed in Medicine Lake and those exposed to the action of sulphate solutions in the laboratory were in sufficiently close agreement to justify the conclusion that the results of laboratory tests of this character may be considered indicative of the performance to be expected under natural conditions of exposure.

2. Concrete fabricated with the cement having a low ratio of alumina to iron was more resistant to sulphate action than was concrete containing the cement having a high ratio.

3. The application of water-gas tar to concrete either by immersion or by brush coating afforded about the same degree of protection. The resistance to sulphate action was greatly increased by the addition of a seal coat of coal tar. The data indicated no appreciable added benefit from immersion in water-gas tar for more than 1 hour or from the application of more than 4 brush coats.

4. Ammonium fluosilicate, alone or in combination with water-gas tar or coal tar, did not afford adequate protection from the action of sulphate waters.

5. Sodium hydroxide, alone or in combination with water-gas tar or coal tar, afforded better protection than similar treatments with ammonium fluosilicate. However, all the treatments with sodium hydroxide were distinctly inferior to the treatment with water-gas tar followed by a seal coat of coal tar.

6. The resistance of the treated concrete was influenced by the character of the concrete and by its curing prior to treatment. Concrete of the richer mix having the lower water-cement ratio was more resistant than concrete of the leaner mix with the higher water-cement ratio. Also concrete cured for a short period (1 day) in air prior to treatment was more resistant than concrete cured for a longer period (7 days).

TABLE 10.—*Protective effect of ammonium fluosilicate and tar on*

Major group No.	Sub-group No.	Crate No.	W/C ratio	Cured		Treatment	Average absorbed		Gain in weight after laboratory storage		
				Moist	Air		Salt	Tar	¼ month	3 to 10 months	11 to 20 months
				Days	*Days*		*Percent*	*Percent*	*Percent*	*Percent* [1]	*Percent* [1]
	1	202	0.8	7	7		1.32		2.78	F (10)	
	2	203	.8	7	28		2.00		3.36	F (9)	
	3	204	.8	28	7		1.04		1.90	F (8)	
5	4	205	.8	28	28	Immersion in ammonium fluosilicate for periods of ½, 1, 4, and 24 hours.	1.17		2.91	F (8)	
	5	206	.7	7	7		1.14		2.28	F (9)	
	6	207	.7	7	28		1.47		3.37	F (8)	
	7	208	.7	28	7		.75		1.84	F (8)	
	8	209	.7	28	28		1.05		2.45	F (7)	
						Group average	1.24		2.61		
	9	210	.8	7	7		1.76	0.45	1.95	2.52 (6)	F (19)
	10	211	.8	7	28		2.22	.51	1.68	3.02 (5)	F (20)
	11	212	.8	28	7	Immersion in ammonium fluosilicate for periods of ½, 1, 4, and 24 hours plus 1 brush coat of coal tar.	.98	.50	1.35	1.88 (5)	F (18)
6	12	213	.8	28	28		1.33	.42	1.62	2.98 (4)	F (19)
	13	214	.7	7	7		1.38	.49	1.69	2.47 (5)	F (18)
	14	215	.7	7	28		1.49	.37	1.69	3.05 (5)	F (17)
	15	216	.7	28	7		.70	.35	.82	2.09 (4)	F (17)
	16	217	.7	28	28		1.03	.42	1.37	2.36 (4)	F (16)
						Group average	1.36	.44	1.52	2.55	
	17	219	.8	7	7		1.80	.53	1.58	1.66 (5)	1.70 (15)
	18	220	.8	7	28		2.49	.61	2.52	2.45 (5)	2.50 (15)
	19	221	.8	28	7	Immersion in ammonium fluosilicate for periods of ½, 1, 4, and 24 hours followed by equal periods of immersion in water-gas tar.	.84	.34	1.30	1.62 (4)	2.28 (14)
7	20	222	.8	28	28		1.26	.41	1.52	1.86 (3)	2.53 (13)
	21	223	.7	7	7		1.38	.42	1.29	1.40 (5)	1.65 (15)
	22	224	.7	7	28		1.85	.57	1.44	1.83 (4)	1.90 (14)
	23	225	.7	28	7		.81	.37	.90	1.17 (3)	1.70 (11)
	24	226	.7	28	28		.83	.45	1.56	1.98 (3)	2.55 (11)
						Group average	1.41	.46	1.50	1.75	2.10
	25	227	.8	7	7		2.00		2.58	3.19 (7)	5.08 (19)
	26	228	.8	7	28		1.84		3.49	4.09 (7)	F (18)
	27	229	.8	28	7		1.43		1.78	2.08 (6)	F (18)
8	28	230	.8	28	28	4 and 6 brush coats of ammonium fluosilicate.	1.52		2.73	3.08 (5)	F (17)
	29	231	.7	7	7		1.67		1.96	2.33 (7)	2.81 (18)
	30	232	.7	7	28		1.55		2.78	3.26 (7)	3.85 (18)
	31	233	.7	28	7		1.33		1.97	2.26 (6)	F (17)
	32	234	.7	28	28		1.31		2.29	2.84 (6)	F (17)
						Group average	1.58		2.45	2.89	
	33	227	.8	7	7		2.06	.43	2.47	3.01 (7)	F (19)
	34	228	.8	7	28		1.78	.39	1.90	3.51 (7)	F (18)
	35	229	.8	28	7		1.40	.42	1.26	1.97 (6)	4.59 (18)
9	36	230	.8	28	28	4 and 6 brush coats of ammonium fluosilicate plus 1 brush coat of coal tar.	1.42	.39	1.17	2.78 (5)	F (17)
	37	231	.7	7	7		1.68	.39	1.63	2.12 (7)	2.34 (18)
	38	232	.7	7	28		1.60	.44	1.43	2.63 (7)	3.31 (18)
	39	233	.7	28	7		1.28	.39	1.22	2.06 (6)	F (17)
	40	234	.7	28	28		1.28	.36	1.21	2.27 (6)	F (17)
						Group average	1.56	.40	1.54	2.54	
	41	235	.8	7	7		1.41	.67	1.48	3.71 (10)	F (20)
	42	236	.8	7	28		1.86	.85	1.65	2.56 (9)	F (20)
	43	237	.8	28	7	4 and 6 brush coats of ammonium fluosilicate plus an average of 3 brush coats of water-gas tar.	1.56	.48	1.11	1.75 (9)	F (20)
10	44	238	.8	28	28		1.52	.40	1.43	2.64 (8)	F (20)
	45	239	.7	7	7		1.40	.50	1.21	1.95 (10)	F (20)
	46	240	.7	7	28		1.72	.79	1.10	1.97 (9)	F (20)
	47	241	.7	28	7		1.27	.32	.71	1.16 (8)	1.54 (19)
	48	242	.7	28	28		1.45	.38	.93	1.92 (7)	
						Group average	1.52	.55	1.20	2.21	

[1] Values for major groups 5, 6, and 7 are based on 12 specimens for laboratory and 24 specimens for lake storage. Values in major groups 8, 9, and 10 are for 6 specimens for laboratory storage and 12 specimens for lake storage for groups 8 and 9, and 24 specimens for lake storage for group 10. F indicates failure of specimens. Figures in parentheses indicate number of months specimens were in solution at time of weighing, or number of months in solution at time of failure.

concrete made with cement A, stored in sulphate solution [1]

Gain in weight after laboratory storage				Number of lake samples attacked and failed after —									
24 to 27 months	30 or 31 months	38 or 39 months	61 months	3 to 8 months	11 to 13 months	15 to 21 months	23 to 25 months	27 to 33 months	35 to 45 months	47 to 53 months	59 to 65 months	72 months	84 months
Percent [1]	*Percent*	*Percent*	*Percent*										
				0 (8)		F (20)							
				0 (7)		0 (19)		F (32)					
				0 (7)		24 (19)		F (31)					
				0 (6)		F (18)							
				0 (8)		18 (20)		F (32)					
				0 (7)		0 (19)		F (32)					
				0 (7)		0 (19)		F (30)					
				0 (6)		0 (18)		F (31)					
				0 (5)		12 (17)		F (30)					
				0 (4)		F (16)							
				0 (4)		4 (16)		12 (28)	F (40)				
				0 (3)		0 (15)		3 (27)	9F (39)	F (52)			
				0 (4)		2 (16)		24 (28)	2F (40)	F (53)			
				0 (4)		0 (16)		6 (28)	18 (40)	18F (53)	F (65)		
				0 (4)		0 (16)		5 (28)	1F (40)	12F (53)	F (65)		
				0 (3)		0 (15)		4 (27)	1F (39)	F (52)			
2.80 (26)		F			0 (13)		4 (25)		18 (37)	18F (52)	F (64)			
2.93 (26)		F			0 (13)		2 (25)		24 (37)	24 (52)	F (64)			
F (25)					0 (13)		10 (25)		17F (37)	F (49)				
F (24)					0 (12)		0 (24)		14 (36)	6F (48)	F (60)			
F (27)					0 (13)		0 (25)		29 (38)	18F (50)	F (62)			
2.11 (25)		2.59	F		0 (12)		0 (24)		4 (36)	4 (48)	4 (60)	3F (72)	12F
F (24)					0 (12)		0 (24)		18 (36)	18F (48)	F (60)		
F (25)					0 (11)		0 (23)		13 (35)	6F (47)	F (59)		
	F			0 (6)		1 (18)		6F (30)	F (42)				
				0 (6)		3 (18)		F (30)					
				0 (5)		6 (17)		F (29)					
				0 (5)		3 (17)		F (29)					
	F			0 (5)		0 (17)		3F (29)	F (41)				
	F			0 (5)		0 (17)		2F (29)	F (41)				
				0 (4)		0 (16)		F (28)					
				0 (4)		0 (16)		F (28)					
				0 (6)		1 (18)		F (30)					
				0 (6)		3 (18)		F (30)					
	F			0 (5)		4 (17)		4F (29)	F (41)				
				0 (5)		2 (17)		6F (29)	F (41)				
	F			0 (5)		0 (17)		4 (29)	F (41)				
	F			0 (5)		0 (17)		6 (29)	6F (41)	F (53)			
				0 (4)		0 (16)		12 (28)	12 (40)	F (52)			
				0 (4)		0 (16)		12 (28)	F (40)				
				0 (8)		2 (21)		18F (33)	F (45)				
				0 (8)		12F (20)		F (32)					
				0 (7)		0 (19)		12F (31)	F (43)				
				0 (6)		0 (18)		12F (30)	F (42)				
				0 (8)		0 (20)		12F (32)	F (44)				
				0 (7)		2 (19)		F (31)					
	F			0 (6)		0 (18)		0 (30)	2F (42)	F (54)			
F				0 (5)		0 (17)		6 (29)	F (41)				

TABLE 11.—*Protective effect of ammonium fluosilicate and tar on*

Major group No.	Subgroup No.	Crate No.	W/C ratio	Cured		Treatment	Average absorbed		Gain in weight		
				Moist	Air		Salt	Tar	¼ month	37 to 46 months	48 to 58 months
				Days	*Days*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
5	1	162	0.8	7	7	Immersion in ammonium fluosilicate for periods of ½, 1, 4, and 24 hours.	1.52		2.80	3.64 (45)	4.22 (55)
	2	163	.8	7	28		2.33		3.37	4.49 (44)	6F (55)
	3	164	.8	28	7		.97		2.29	2.99 (44)	3.14 (56)
	4	165	.8	28	28		1.13		3.17	4.05 (44)	4.46 (55)
	5	166	.7	7	7		1.09		2.30	2.97 (45)	3.11 (56)
	6	167	.7	7	28		1.66		3.16	3.74 (44)	4.24 (55)
	7	168	.7	28	7		.66		1.68	2.46 (43)	2.73 (54)
	8	169	.7	28	28		.76		2.29	3.12 (43)	3.30 (54)
						Group average	1.26		2.63	3.43	3.79
6	9	170	.8	7	7	Immersion in ammonium fluosilicate for periods of ½, 1, 4, and 24 hours plus 1 brush coat of coal tar.	2.08	0.37	2.44	3.20 (44)	3.20 (55)
	10	171	.8	7	28		3.07	.27	1.37	3.84 (42)	3.99 (52)
	11	172	.8	28	7		1.13	.28	.68	2.17 (42)	2.17 (53)
	12	173	.8	28	28		1.65	.34	1.17	2.95 (41)	2.95 (52)
	13	174	.7	7	7		1.25	.36	1.15	2.31 (42)	2.31 (54)
	14	175	.7	7	28		1.80	.31	1.41	2.80 (40)	2.80 (52)
	15	176	.7	28	7		.58	.30	.65	1.88 (41)	1.88 (53)
	16	177	.7	28	28		.87	.30	.46	2.29 (41)	2.35 (52)
						Group average	1.55	.32	1.17	2.68	2.71
7	17	178	.8	7	7	Immersion in ammonium fluosilicate for periods of ½, 1, 4 and 24 hours followed by equal periods of immersion in water-gas tar.	2.72	1.50	1.50	2.24 (40)	2.24 (52)
	18	179	.8	7	28		3.11	.97	2.10	2.71 (38)	2.71 (50)
	19	181	.8	28	7		.83	.72	1.57	2.14 (44)	2.26 (52)
	20	180	.8	28	28		1.38	.72	2.08	2.78 (37)	2.81 (48)
	21	182	.7	7	7		1.69	.95	1.24	1.85 (38)	1.96 (50)
	22	183	.7	7	28		2.27	.62	2.35	2.91 (37)	2.91 (49)
	23	184	.7	28	7		.77	.60	1.39	2.02 (45)	2.06 (56)
	24	185	.7	28	28		.89	.55	2.00	2.29 (43)	2.29 (55)
						Group average	1.71	.83	1.78	2.36	2.40
8	25	186	.8	7	7	4 and 6 brush coats of ammonium fluosilicate.	3.52		3.43	4.30 (46)	4.51 (58)
	26	187	.8	7	28		3.28		4.70	F (43)	
	27	188	.8	28	7		1.40		2.28	2.50 (43)	2.80 (55)
	28	189	.8	28	28		1.62		3.12	3.39 (43)	3.95 (55)
	29	190	.7	7	7		3.18		3.20	3.53 (41)	3.77 (53)
	30	191	.7	7	28		2.67		3.51	4.10 (41)	4.36 (53)
	31	192	.7	28	7		1.70		2.33	2.64 (42)	2.75 (54)
	32	193	.7	28	28		1.92		2.68	3.09 (42)	3.24 (54)
						Group average	2.41		3.15		
9	33	186	.8	7	7	4 and 6 brush coats of ammonium fluosilicate plus 1 brush coat of coal tar.	3.37	.44	3.03	4.26 (45)	4.36 (57)
	34	187	.8	7	28		3.43	.51	4.15	F (44)	
	35	188	.8	28	7		1.25	.48	.95	1.91 (43)	1.91 (55)
	36	189	.8	28	28		1.62	.50	1.32	2.90 (42)	2.96 (55)
	37	190	.7	7	7		2.91	.44	3.13	3.47 (41)	3.46 (53)
	38	191	.7	7	28		2.71	.41	3.22	3.86 (41)	3.86 (53)
	39	192	.7	28	7		1.71	.41	1.21	1.99 (42)	2.09 (54)
	40	193	.7	28	28		1.90	.55	.97	2.68 (42)	2.77 (54)
						Group average	2.36	.47	2.25		
10	41	194	.8	7	7	4 and 6 brush coats of ammonium fluosilicate plus an average of 2 brush coats of water-gas tar.	3.59	1.02	2.28	2.69 (41)	2.76 (53)
	42	195	.8	7	28		3.19	.53	3.45	3.73 (39)	3.75 (52)
	43	196	.8	28	7		2.13	.20	1.65	2.19 (38)	2.19 (51)
	44	197	.8	28	28		2.05	.25	3.07	3.40 (37)	3.40 (50)
	45	198	.7	7	7		3.19	.34	2.13	2.64 (39)	2.72 (52)
	46	199	.7	7	28		2.26	.40	2.58	3.01 (38)	3.06 (51)
	47	200	.7	28	7		1.67	.25	1.03	1.56 (37)	1.63 (50)
	48	201	.7	28	28		2.57	.28	1.93	2.61 (37)	2.61 (49)
						Group average	2.58	.41	2.51	2.73	2.76

[1] Values for major groups 5, 6, and 7 are based on 12 specimens for laboratory and 24 specimens for lake storage. Values in major groups 8, 9, and 10 are for 6 specimens for laboratory storage and 12 specimens for lake storage in the case of major groups 8 and 9, and 24 specimens for lake storage for major group 10. F indicates failure of specimens. Figures in parentheses indicate number of months specimens were in solution at time of weighing, or number or months in solution at time of failure.

concrete made with cement B and stored in sulphate solution [1]

after laboratory storage				Number of lake specimens attacked and failed after—									
60 to 69 months	73 to 93 months	85 to 105 months	102 to 106 months	1 to 11 months	12 to 23 months	24 to 35 months	36 to 47 months	48 to 59 months	61 to 71 months	72 to 83 months	84 to 95 months	96 to 101 months	102 to 113 months
Percent	*Percent*	*Percent*	*Percent*										
4.77 (69)	5.63 (93)	F (105)		0 (7)	0 (19)	24 (31)	24 (43)	24 (55)	24 (67)	18F (79	F (91)		
7F (67)	F (92)			0 (6)	0 (18)	24 (30)	F (42)						
3.45 (69)	3F (93)	6F (105)	6F (122)	0 (7)	0 (19)	12 (31)	18 (43)	24 (55)	24 (67)	12F (79)	F (91)		
5.47 (68)	F (92)			0 (6)	0 (18)	0 (30)	9 (42)	24 (54)	6F (66)	6F (78)	F (90)		
3.50 (68)	F (92)			0 (8)	0 (20)	12 (32)	24 (44)	24 (56)	24 (68)	12F (80)	F (92)		
5.02 (68)	F (92)			0 (6)	0 (18)	12 (30)	18 (42)	24 (54)	24 (66)	24 (78)	F (90)		
2.89 (67)	6F (91)	6F (103)	6F (120)	0 (6)	0 (18)	6 (30)	6 (42)	24 (54)	24 (66)	24 (78)	F (90)		
3.40 (67)	F (91)			0 (6)	0 (18)	0 (30)	0 (42)	24 (54)	24 (66)	24 (78)	F (90)		
4.21													
3.20 (67)	3.68 (91)	3.81 (103)	3.81 (121)	0 (5)	0 (17)	0 (29)	5 (41)	6 (53)	24 (65)	24 (77)	1F (89)	1F (101)	1F (113)
4.96 (65)	6F (89)	6F (101)	7F (118)	0 (3)	0 (15)	0 (27)	7 (39)	24 (51)	6F (63)	F (75)			
2.17 (66)	2.43 (90)	2.55 (101)	2.55 (119)	0 (4)	0 (16)	0 (28)	3 (40)	3 (52)	4 (64)	4 (76)	4 (88)	4 (100)	4 (112)
3.37 (65)	3.58 (89)	3.81 (101)	3.81 (119)	0 (3)	0 (15)	0 (27)	0 (39)	5 (51)	24 (63)	24 (75)	18F (87)	5F (99)	
2.39 (66)	2.61 (90)	2.73 (102)	2.73 (119)	0 (4)	0 (16)	0 (28)	2 (40)	2 (52)	5 (64)	5 (76)	5 (88)	5 (100)	24 (112)
2.84 (64)	3.19 (89)	3.34 (101)	3.34 (116)	0 (3)	0 (15)	0 (27)	3 (39)	6 (51)	6 (63)	6 (75)	21 (87)	3F (99)	4F (111)
1.94 (65)	2.16 (89)	2.26 (101)	2.26 (119)	0 (4)	0 (16)	0 (28)	1 (40)	1 (52)	1 (64)	1 (76)	1 (88)	1 (100)	1 (112)
2.48 (65)	2.71 (89)	2.79 (101)	2.79 (119)	0 (3)	0 (15)	0 (27)	0 (39)	1 (51)	1 (63)	1 (75)	1 (87)	2 (99)	11 (110)
2.92													
2.32 (64)	2.64 (88)	2.73(100)	2.73 (117)	0 (2)	0 (14)	0 (26)	0 (38)	6 (50)	15 (62)	15 (74)	24 (86)	24 (98)	1F (110)
2.71 (62)	2.92 (87)	2.98 (99)	2.98 (116)	0 (1)	0 (13)	0 (25)	0 (37)	0 (49)	0 (61)	0 (73)	1 (85)	1 (97)	2 (109)
2.26 (62)	2.85 (80)	3.08 (92)	3.08 (110)	0 (7)	0 (19)	0 (31)	0 (43)	12 (55)	15 (67)	11F (79)	18F (91)		18F(103)
2.97 (60)	3.25 (85)	3.41 (97)	3.41 (114)	0 (11)	0 (23)	0 (35)	0 (47)	0 (59)	0 (71)	1 (83)	3 (95)		10 (107)
1.99 (63)	2.25 (87)	2.43 (99)	2.43 (116)	0 (1)	0 (13)	0 (25)	0 (37)	0 (49)	0 (61)	2 (73)	6 (85)	18 (97)	18 (109)
2.91 (61)	3.17 (86)	3.31 (98)	3.31 (115)	0 (1)	0 (12)	0 (24)	0 (36)	1 (48)	1 (60)	1 (72)	1 (84)	1 (96)	1 (108)
	2.34 (80)	2.48 (92)	2.48 (110)	0 (7)	0 (18)	0 (30)	0 (42)	9 (54)	12 (66)	18 (78)	24 (90)		24 (103)
2.49 (68)	2.91 (80)	3.06 (92)	3.06 (109)	0 (6)	0 (18)	0 (30)	1 (42)	7 (54)	9 (66)	18 (78)	24 (90)		24 (102)
	2.79	2.93	2.93										
	3F (81)	3F (93)	F (111)	0 (8)	0 (20)	0 (32)	12 (44)	F (56)					
				0 (6)	0 (18)	0 (30)	12 (42)	F (54)					
	3.55 (79)	3.74 (91)	F (108)	0 (5)	0 (17)	0 (29)	0 (41)	6 (53)	6 (65)	F (77)			
	F (79)			0 (5)	0 (17)	0 (29)	12 (41)	6F (53)	F (65)				
	4.24 (77)	4.34 (89)	4.34 (106)	0 (3)	0 (15)	0 (27)	0 (39)	0 (51)	6 (63)	6 (75)	6F (87)	6F (99)	
	3F (76)	3F (88)	F (106)	0. (4)	0 (16)	0 (28)	12 (40)	12 (52)	F (64)				
	3.18 (78)	3.31 (90)	3.31 (107)	.0 (4)	0 (16)	0 (28)	0 (40)	0 (52)	12 (64)	12 (76)	12 (88)	5F (100)	
	3F (78)	3F (90)	F (107)	0 (5)	0 (17)	0 (29)	12 (41)	12 (53)	12 (65)	F (77)			
	4.65 (81)	4.79 (93)	4.81 (111)	0 (8)	0 (20)	0 (32)	0 (44)	0 (56)	0 (68)	6 (80)	12 (92)		12 (104)
				0 (6)	0 (18)	0 (30)	6 (42)	12 (54)	12 (66)	F (78)			
	1.99 (79)	2.11 (91)	2.11 (108)	0 (5)	0 (17)	0 (29)	0 (41)	0 (53)	0 (65)	0 (77)	0 (89)	0 (101)	
	3.37 (79)	3.49 (91)	3.49 (108)	0 (5)	0 (17)	0 (29)	0 (41)	4 (53)	12 (65)	F (77)			
	3.67 (77)	3.78 (89)	3.78 (106)	0 (3)	0 (15)	0 (27)	0 (39)	0 (51)	0 (63)	0 (75)	0 (87)	6 (99)	
	4.10 (76)	4.17 (88)	4.17 (106)	0 (4)	0 (16)	0 (28)	0 (40)	0 (52)	0 (64)	0 (76)	2 (88)	11 (100)	
	2.27 (78)	2.40 (90)	2.40 (107)	0 (4)	0 (16)	0 (28)	0 (40)	0 (52)	0 (64)	0 (76)	0 (88)	0 (100)	
	3.01 (78)	3.08 (90)	3.08 (107)	0 (5)	0 (17)	0 (29)	0 (41)	0 (53)	0 (65)	0 (77)	0 (89)	7 (101)	
	3.09 (77)	3.23 (89)	3.23 (106)	0 (3)	0 (15)	0 (27)	0 (39)	2 (51)	18 (63)	12F (75)	12F (87)	F (99)	
	4.15 (76)	4.34 (88)	4.34 (105)	0 (2)	0 (14)	0 (26)	0 (38)	2 (50)	6F (62)	18F (74)	18F (86)	F (98)	
	2.27 (75)	2.40 (87)	2.47 (104)	0 (1)	0 (13)	0 (25)	0 (37)	0 (49)	0 (61)	0 (72)	0 (84)	8 (97)	
	3.67 (74)	3.80 (86)	3.80 (103)	0 (1)	0 (12)	0 (24)	0 (36)	0 (48)	0 (60)	0 (72)	0 (84)	0 (96)	
	3.02 (76)	3.15 (88)	3.15 (105)	0 (2)	0 (14)	0 (26)	0 (38)	0 (50)	0 (62)	3 (74)	11 (86)	24 (98)	
	3.30 (75)	3.42 (87)	3.42 (104)	0 (1)	0 (13)	0 (25)	0 (37)	0 (49)	6 (61)	12 (72)	6F (84)	F (97)	
	1.90 (74)	2.04 (86)	2.04 (103)	0 (1)	0 (12)	0 (24)	0 (36)	0 (48)	0 (60)	0 (72)	0 (84)	12 (96)	
	2.76 (73)	2.94 (85)	2.94 (102)	0 (11)	0 (23)	0 (35)	0 (47)	0 (59)	0 (71)	0 (83)	0 (95)		
	3.02	3.16	3.17										

TABLE 12.—*Protective effect of sodium hydroxide on concrete made with cement A and stored in sulphate solution* [1]

Major group No.	Sub-group No.	W/C Ratio	Cured: Moist	Cured: Air	Treatment	Average absorbed: Sodium hydroxide	Average absorbed: Tar	Gain in weight after laboratory storage: ¼ month	2 to 9 months	15 to 21 months	27 to 29 months	40 or 41 months	51 to 64 months	64 to 76 months	93 months
			Days	*Days*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
5-S	1	0.8	7	7	Immersion in sodium hydroxide for periods of ½, 1, 4, and 24 hours.	1.95		2.03	2.99 (6)	F (19)					
	2	.8	7	28		2.13		2.72	4.22 (6)	F (19)					
	3	.8	28	7		1.00		1.66	2.57 (6)	F (19)					
	4	.8	28	28		1.42		2.02	5.22 (6)	F (19)					
	5	.7	7	7		1.50		1.44	2.58 (6)	F (19)					
	6	.7	7	28		1.73		2.16	3.19 (6)	F (19)					
	7	.7	28	7		.85		1.35	1.90 (6)	F (19)					
	8	.7	28	28		1.19		1.55	2.69 (6)	F (18)					
					Group average	1.47		1.87	3.17						
6-S	9	.8	7	7	Immersion in sodium hydroxide for periods of ½, 1, 4, and 24 hours plus 1 brush coat of coal tar.	1.66	0.47	.69	.92 (3)	1.07 (16)	1.37 (27)	2.06	F (64)		
	10	.8	7	28		2.37	.40	.69	1.15 (3)	1.24 (16)	1.90 (27)	3.63	F (64)		
	11	.8	28	7		1.24	.46	.84	1.21 (3)	1.67 (16)	2.50 (27)	3.26	F (63)		
	12	.8	28	28		1.36	.49	.79	1.33 (3)	1.59 (16)	2.80 (27)	F			
	13	.7	7	7		1.30	.43	.66	.88 (3)	1.04 (16)	1.15 (27)	1.40	1.80 (64)	1.96 (76)	3F (93)
	14	.7	7	28		1.82	.40	.81	1.19 (3)	1.28 (16)	1.70 (27)	2.14	2.90 (64)	F (76)	
	15	.7	28	7		1.03	.49	.73	.97 3)	1.02 (16)	1.25 (27)	2.03	F (63)		
	16	.7	28	28		1.25	.46	.62	.97 (3)	1.01 (16)	1.32 (27)	1.63	F (63)		
					Group average	1.50	.45	.73	1.08	1.24	1.74				
7-S	17	.8	7	7	Immersion in sodium hydroxide for periods of ½, 1, 4, and 24 hours followed by equal periods of immersion in water-gas tar.	1.55	.58	.69	2.70 (9)	F (20)					
	18	.8	7	28		2.32	.67	.89	2.23 (8)	F (19)					
	19	.8	28	7		1.06	.50	.64	2.37 (8)	F (21)					
	20	.8	28	28		1.30	.33	.91	3.15 (8)	F (20)					
	21	.7	7	7		1.17	.49	.48	1.63 (9)	F (20)					
	22	.7	7	28		2.02	.62	.72	1.64 (8)	F (19)					
	23	.7	28	7		.81	.44	.43	1.23 (8)	F (19)					
	24	.7	28	28		1.16	.31	.71	2.00 (8)	F (20)					
					Group average	1.42	.49	.68	2.12						
8-S	25	.8	7	7	4 and 6 brush coats of sodium hydroxide.	1.94		2.87	3.35 (4)	F (16)					
	26	.8	7	28		1.77		3.24	3.76 (4)	F (16)					
	27	.8	28	7		1.26		2.10	2.36 (4)	F (16)					
	28	.8	28	28		1.47		2.39	3.01 (4)	F (16)					
	29	.7	7	7		1.66		2.40	2.80 (4)	F (16)					
	30	.7	7	28		1.59		2.34	3.00 (4)	F (19)					
	31	.7	28	7		1.38		1.25	1.66 (4)	3.45 (16)	F (28)				
	32	.7	28	28		1.29		1.52	2.08 (4)	4.76 (16)	F (28)				
					Group average	1.54		2.26	2.75						
9-S	33	.8	7	7	4 and 6 brush coats of sodium hydroxide plus 1 brush coat of coal tar.	1.93	.44	.58	1.20 (4)	1.48 (16)	1.82 (27)		3.02 (52)	F (65)	
	34	.8	7	28		1.77	.38	.71	1.42 (4)	1.75 (16)	2.18 (29)		3.77 (52)	F (65)	
	35	.8	28	7		1.23	.38	.58	.93 (4)	1.60 (16)	F (28)				
	36	.8	28	28		1.43	.36	.51	1.26 (4)	2.61 (16)	F (28)				
	37	.7	7	7		1.63	.41	.42	.93 (4)	1.25 (16)	1.74 (28)		2.79 (52)	F (65)	
	38	.7	7	28		1.54	.38	.66	1.36 (4)	1.70 (16)	2.09 (28)		3.47 (52)	F (64)	
	39	.7	28	7		1.44	.39	.39	.86 (4)	1.05 (16)	1.41 (28)		F (52)		
	40	.7	28	28		1.29	.31	.22	.91 (4)	1.82 (16)	1.88 (28)		F (51)		
					Group average	1.53	.38	.51	1.11	1.66					
10-S	41	.8	7	7	4 and 6 brush coats of sodium hydroxide plus an average of 4 brush coats of water-gas tar.	1.38	.81	.84	1.66 (5)	F (18)					
	42	.8	7	28		1.48	.85	.90	1.80 (4)	F (17)					
	43	.8	28	7		1.28	.53	.89	1.04 (3)	F (16)					
	44	.8	28	28		1.41	.39	1.77	2.67 (3)	F (16)					
	45	.7	7	7		1.33	.83	.82	1.18 (5)	2.37 (17)		F (41)			
	46	.7	7	28		1.50	.78	1.19	1.75 (3)	2.67 (16)		F (40)			
	47	.7	28	7		1.62	.55	.84	1.16 (3)	F (16)					
	48	.7	28	28		1.33	.43	1.20	1.76 (2)	F (15)					
					Group average	1.42	.65	1.06	1.63						

[1] Values are based on 12 specimens for major groups 5-S, 6-S, and 7-S, and on 6 specimens for groups 8-S, 9-S, and 10-S. F indicates failure of specimens. Figures in parentheses indicate number of months specimens were in solution at time of weighing or number of months in solution at time of failure.

DETERMINATION OF CEMENT CONTENT OF SOIL-CEMENT MIXTURES

BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION

Reported by JACOB MIZROCH, Assistant Chemical Engineer

CHEMICAL ANALYSES made during the construction of soil-cement base courses have been of value in locating and controlling discrepancies between required percentages of cement and the amounts actually present. This information is also useful in studies of the pavement during its service life.

In 1939 and 1940 several State Highway Departments began to make chemical analyses as a control measure on soil-cement work. This led to a preliminary survey by Subcommittee No. 2 of the Project Committee on "Stabilized Roads" of the Highway Research Board to determine the methods of analysis in use and their relative merits.

The survey showed that 2 basic methods were in use. At the request of the subcommittee, 23 laboratories cooperated in testing standard soil-cement samples by the 2 methods. The results of these cooperative tests are reported by Carson and Reid in the Proceedings of the Highway Research Board.[1]

Of the 2 basic methods used, method 1 involves determination of the calcium oxide (CaO) content of raw soil, cement, and soil-cement mixtures, and calculation of the percentage of cement in the soil-cement mixtures using the proportionality law applied to mixtures. Method 2 involves determination of the calcium (Ca) content of a sample of soil-cement mixture from the completed roadway and a similar determination on a control sample prepared to contain approximately the same percentage of cement, using the original raw soil and cement as components. From these 2 values the percentage of cement in the roadway sample may be calculated.

Both methods require the removal of silica, iron, and alumina before the subsequent precipitation and determination of calcium. In method 1, three steps are necessary since silica is first filtered off and then iron and alumina are precipitated, filtered off, redissolved, reprecipitated and filtered off a second time. In method 2, the iron and alumina are precipitated in the presence of silica and filtered off together with it, hence saving two steps in the procedure.

In the control of soil-cement construction it is necessary to have a rapid method of determining chemically the cement content of the soil-cement mixtures. From this viewpoint, method 2 is more desirable than method 1 because of the saving in time. However, the subcommittee has recommended method 1 as the more suitable of the two, because of its inherent accuracy and wider applicability.

A procedure combining the accuracy of method 1 and the shortness of method 2 is desirable.

Such a procedure has been worked out at the laboratory of the Public Roads Administration based on the principles brought out by the work of Chapman,[2] and McComas and Rieman[3] on methods of determining calcium in the presence of iron, alumina, and other interfering ions. These investigators found that calcium can be precipitated as the oxalate in the presence of iron, alumina, etc., if the solution is buffered with sufficient ammonium chloride and various organic acids at pH4.

The Public Roads method, therefore, embodies the following procedure: The samples of soil, soil-cement, and cement are treated with hydrochloric acid, the insoluble residue is filtered off, and calcium is precipitated and determined in the filtrate after sufficiently buffering with ammonium chloride and acetic acid and adjusting the solution to a pH of 4.

Determinations of percentage of cement by this method are fully as accurate as determinations on the same samples by subcommittee method 1. The time required for the analysis by this method is the same as that required by method 2 of the subcommittee. The saving in time over that necessary for subcommittee method 1 amounts to approximately one-half hour per sample.

PREPARATION OF REAGENT SOLUTIONS

Potassium permanganate, 0.1 N.—3.2 gm. $KMnO_4$ is dissolved in 1 l. of distilled water and the solution is heated in a covered beaker for 3 hours at 90° to 95° C., then set aside at room temperature for several days. The solution is then filtered through asbestos and standardized against pure oven-dried sodium oxalate.

Acetic acid, 10 percent.—100 ml. glacial acetic acid is diluted to 1 l. with distilled water.

Oxalic acid, 10 percent.—To 100 gm. oxalic acid is added 400 ml. distilled water and the whole warmed until the crystals dissolve. The solution is filtered into a clean liter flask and diluted to 1 l. with distilled water.

Ammonium chloride, 30 percent.—300 gm. of NH_4Cl is placed in a liter beaker and enough distilled water added to make beaker about four-fifths full. The mixture is stirred, warmed to room temperature and then filtered on 9 cm. grade A, B and A filter paper into a clean liter flask. The undissolved residue is brought on the filter with a stream of distilled water from a wash bottle and dissolved by repeated additions of a few milliliters water to the filter. When all of the salt is in solution, the filtrate is diluted to a liter with distilled water.

Brom-cresol green indicator, 0.04 percent solution.—This indicator solution may be obtained from the LaMotte Chemical Co., Baltimore, Md.

[1] Chemical Determination of Cement Content of Soil-Cement Mixtures from Cement Hardened Bases. By L. S. Carson and Carl Reid. Proceedings, Twenty-first Annual Meeting of the Highway Research Board, p. 471 (1941).

[2] The Precipitation of Calcium Oxalate in the Presence of Iron, Aluminum, Titanium, Manganese, Magnesium, and Phosphorus. H. D. Chapman. Soil Science, vol. 26, p. 479 (1928).

[3] Accurate Determination of Calcium Without Reprecipitation. W. H. McComas and W. Rieman. Industrial and Engineering Chemistry, Analytical Edition, vol. 14, p. 929 (1942).

METHOD OF ANALYSIS DESCRIBED

Soil-cement mixtures.—The soil-cement mixture is air dried, then pulverized to pass the No. 40 sieve. About 50 gm. of the mixture is oven dried at 110° C. to constant weight, then cooled and 1 gm. weighed into a 100 ml. beaker. Ten ml. 1:1 HCl is added, the beaker covered and the solution boiled on a hot plate for 5 minutes. The insoluble residue is filtered off on 7 or 9 cm. grade A, B and A filter paper (or equivalent) and washed chloride-free with hot distilled water (about five washings, after all the residue has been brought on the filter paper) the filtrate being caught in a 250-ml. beaker. Now 10 ml. 30 percent ammonium chloride solution, 10 ml. 10 percent oxalic acid and 10 ml. 10 percent acetic acid are added and the solution diluted to 150 ml.

Ten ml. 30 percent NH_4Cl insures the presence of at least 6 gm. NH_4Cl in the solution when the pH is adjusted to 4. The quantities of reagents given are for soils or soil-cement mixtures containing less than 10 percent acid-soluble iron and aluminum oxides. For soils containing more than 10 percent acid-soluble iron and aluminum oxides, the amounts of reagents given are insufficient to give a satisfactory precipitate of calcium oxalate. When soils with between 10 and 20 percent soluble iron and aluminum oxides were tested, it was found that the quantities of reagents had to be increased to 20 ml. 30 percent NH_4Cl, 15 ml. 10 percent oxalic acid and 15 ml. 10 percent acetic acid. The volume of the solution also had to be increased to 200 ml.

The diluted solution is heated nearly to boiling and 11 ml. 1:1 ammonia is added with stirring. A drop of brom-cresol green indicator is then added. If the drop turns green, the solution is at pH4. If it turns yellow, not enough ammonia had been added; if the drop turns blue, the solution is too basic and a few drops of 5 NHCl must be added till the desired pH is attained. The cloudy solution, now at pH4, is boiled gently for 5 minutes on the hot plate and then set on a cooler portion of the hot plate (or on a steam bath) for an hour for the calcium oxalate to settle out. The calcium oxalate is then filtered off on 7 cm. 00 Munktell filter paper (or equivalent grade), the beaker is rinsed three times with hot distilled water and the precipitate is washed five times with the hot water.

The filter paper is transferred to the rinsed beaker, then 50 ml. hot distilled water, and 5 ml. 1:1 H_2SO_4 are added. The filter paper is opened with a glass rod and the solution is stirred till all the calcium oxalate is in solution. The paper is now lifted with the glass rod, thoroughly rinsed with hot distilled water into the beaker and finally balled up between thumb and forefinger, squeezed dry, and discarded. The solution is heated to between 80° and 90° C. and immediately titrated with 0.1 N standard $KMnO_4$ solution.

$$1 \text{ ml. } 0.1 \text{ N} KMnO_4 = 0.0028 \text{ gm} CaO$$

Untreated soil.—Same procedure is followed as for the soil-cement mixtures.

Cement.—One gm. oven-dried cement is weighed out into a 100 ml. beaker; 50 ml. 1:4 HCl is added and the beaker covered. The solution is boiled 5 minutes on the hot plate and the insoluble residue filtered off, the filtrate being caught in a 250 ml. volumetric flask. When the residue is washed chloride-free the contents of the flask are cooled and the volume adjusted to 250 ml. A 25-ml. aliquot portion is pipetted into a 250-ml. beaker and 4 ml. concentrated HCl added. From this point on the procedure follows exactly the procedure for precipitation and determination of calcium described in the section on soil-cement mixtures.

Calculations:

Let A = percentage CaO in the soil-cement mixture.
B = percentage CaO in the untreated soil.
C = percentage CaO in the cement.

Then $\frac{A-B}{C-B} \times 100$ = percentage cement in the soil-cement mixture.

Alternate method of calculation:

$$\frac{\text{ml. } KMnO_4 \text{ required for 1 gm. soil-cement} - \text{ml. } KMnO_4 \text{ required for 1 gm. untreated soil}}{\text{ml. } KMnO_4 \text{ required for 1 gm. cement} - \text{ml. } KMnO_4 \text{ required for 1 gm. untreated soil}} \times 100 = \text{percentage cement in soil-cement}$$

This alternate method of calculation has the advantage of doing away with the necessity of standardizing the potassium permanganate solution.

NEW METHOD GIVES SATISFACTORY RESULTS

To test the accuracy of this method, determinations of percentages of cement in soil-cement mixtures were made by this method as well as by that recommended by the subcommittee. Table 1 gives the results on samples obtained by crushing and pulverizing to pass the No. 40 sieve some soil-cement cylinders which had been subjected to 12 cycles of wetting and drying. Table 2 gives the results on samples obtained by crushing and pulverizing air-dry clay-cement cylinders which had been cured in the moist closet for 7 days.

TABLE 1.—*Percentages of calcium oxide and cement, and grams of cement per 100 gm. of soil found by 2 methods*

[Tests made on soil-cement cylinders subjected to 12 cycles of wetting and drying and pulverized to pass the No. 40 sieve]

Sample	CaO		Cement		Cement per 100 gm. of soil	
	Subcommittee method	Public Roads method	Subcommittee method	Public Roads method	Subcommittee method	Public Roads method
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Gm.*	*Gm.*
Soil	0.28	0.29				
5A, 5 gm. cement per 100 gm. soil	3.33	3.33	4.9	4.9	5.2	5.2
7A, 7 gm. cement per 100 gm. soil	4.62	4.59	7.0	7.0	7.6	7.5
9A, 9 gm cement per 100 gm. soil	5.35	5.29	8.2	8.1	8.9	8.8
5B, 5 gm. cement per 100 gm. soil	3.27	3.32	4.9	4.9	5.2	5.2
7B, 7 gm. cement per 100 gm. soil	4.46	4.44	6.8	6.8	7.3	7.3
9B, 9 gm. cement per 100 gm. soil	5.32	5.40	8.2	8.3	8.9	9.0
Cement	61.95	61.75				

TABLE 2.—*Percentages of calcium oxide and cement and grams of cement per 100 gm. clay found by 2 methods.*

[Tests made on air-dry clay-cement cylinders cured in moist closet 7 days and pulverized to pass the No. 40 sieve]

Sample	CaO		Cement		Cement per 100 gm. of clay	
	Subcommittee method	Public Roads method	Subcommittee method	Public Roads method	Subcommittee method	Public Roads method
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Gm.*	*Gm.*
NEW YORK AVENUE CLAY	0.18	0.16				
3 gm. cement No. 1 per 100 gm. clay	2.02	2.00	2.9	2.9	3.0	3.0
7 gm. cement No. 1 per 100 gm. clay	4.26	4.24	6.5	6.5	6.9	6.9
11 gm. cement No. 1 per 100 gm. clay	6.26	6.23	9.7	9.6	10.7	10.6
Cement No. 1	62.80	63.20				
3 gm. cement No. 2 per 100 gm. clay	1.93	1.92	2.9	2.9	3.0	3.0
7 gm. cement No. 2 per 100 gm. clay	4.12	4.04	6.4	6.3	6.8	6.7
11 gm. cement No. 2 per 100 gm. clay	5.94	6.02	9.4	9.5	10.4	10.5
Cement No. 2	61.30	61.78				
3 gm. cement No. 3 per 100 gm. clay	2.04	2.03	2.9	2.9	3.0	3.0
7 gm. cement No. 3 per 100 gm. clay	4.20	4.28	6.2	6.4	6.7	6.8
11 gm. cement No. 3 per 100 gm. clay	6.33	6.32	9.6	9.5	10.6	10.5
Cement No. 3	64.55	64.78				
3 gm. cement No. 4 per 100 gm. clay	1.94	1.96	2.8	2.9	2.9	3.0
7 gm. cement No. 4 per 100 gm. clay	4.07	4.09	6.3	6.3	6.7	6.7
11 gm. cement No. 4 per 100 gm .clay	6.14	6.15	9.6	9.6	10.6	10.6
Cement No. 4	62.30	62.75				
3 gm. cement No. 5 per 100 gm. clay	1.99	1.99	2.9	2.9	3.0	3.0
7 gm. cement No. 5 per 100 gm. clay	4.12	4.13	6.2	6.2	6.6	6.6
11 gm. cement No. 5 per 100 gm. clay	6.16	6.12	9.4	9.3	10.4	10.3
Cement No. 5	63.50	63.92				
3 gm. cement No. 6 per 100 gm. clay	1.99	1.98	2.9	2.9	3.0	3.0
7 gm. cement No. 6 per 100 gm. clay	4.12	4.19	6.3	6.4	6.7	6.8
11 gm. cement No. 6 per 100 gm. clay	6.20	6.25	9.6	9.6	10.6	10.6
Cement No. 6	63.10	63.60				
CECIL CLAY	None	None				
3 gm. cement No. 1 per 100 gm. clay	1.90	1.83	3.0	2.9	3.1	3.0
7 gm. cement No. 1 per 100 gm. clay	4.11	4.08	6.5	6.5	6.9	6.9
11 gm. cement No. 1 per 100 gm. clay	6.23	6.14	9.9	9.7	11.0	10.7
Cement No. 1	62.80	63.20				
3 gm. cement No. 2 per 100 gm. clay	1.82	1.75	3.0	2.8	3.1	2.9
7 gm. cement No. 2 per 100 gm. clay	3.98	3.90	6.5	6.3	6.9	6.7
11 gm. cement No. 2 per 100 gm. clay	5.97	5.94	9.7	9.6	10.7	10.6
Cement No. 2	61.30	61.78				
3 gm. cement No. 3 per 100 gm. clay	1.91	1.90	3.0	2.9	3.0	3.0
7 gm. cement No. 3 per 100 gm. clay	4.18	4.17	6.5	6.4	6.9	6.8
11 gm. cement No. 3 per 100 gm. clay	6.28	6.26	9.7	9.7	10.7	10.7
Cement No. 3	64.55	64.78				
3 gm. cement No. 4 per 100 gm. clay	1.87	1.81	3.0	2.9	3.1	3.0
7 gm. cement No. 4 per 100 gm. clay	4.03	4.03	6.5	6.4	6.9	6.8
11 gm. cement No. 4 per 100 gm. clay	6.00	6.03	9.6	9.6	10.6	10.6
Cement No. 4	62.30	62.75				
3 gm. cement No. 5 per 100 gm. clay	1.89	1.88	3.0	2.9	3.1	3.0
7 gm. cement No. 5 per 100 gm. clay	4.12	4.06	6.5	6.4	6.9	6.8
11 gm. cement No. 5 per 100 gm. clay	6.21	6.19	9.8	9.7	10.8	10.7
Cement No. 5	63.50	63.92				
3 gm. cement No. 6 per 100 gm. clay	1.94	1.90	3.1	3.0	3.2	3.1
7 gm. cement No. 6 per 100 gm. clay	4.18	4.09	6.6	6.4	7.1	6.9
11 gm. cement No. 6 per 100 gm. clay	6.12	6.17	9.7	9.7	10.7	10.7
Cement No. 6	63.10	63.60				

In 4 of the 6 mixed samples listed in table 1, the percentages of cement found by the 2 methods are identical. Of the remaining 2 samples, the Public Roads method gives a result 0.1 percent lower in 1 case and 0.1 percent higher in the other. Of the 36 samples listed in table 2, the 2 methods give identical results on 14 samples. The results obtained by the Public Roads method are 0.1 percent lower on 14 samples, 0.2 percent lower on 4, 0.1 percent higher on 3, and 0.2 percent higher on 1.

These differences are listed in table 3, columns 3 and 6. The average of the algebraic sum of the differences is −0.4 percent. This minus value shows that the Public Roads method tends to give slightly lower values for the cement content of soil-cement mixtures than the method recommended by the subcommittee.

TABLE 3.—*Differences in cement content found by the two methods*

Subcommittee method	Public Roads method	Difference	Subcommittee method	Public Roads method	Difference
Percent	*Percent*		*Percent*	*Percent*	
4.9	4.9		2.9	2.9	
7.0	7.0		6.3	6.4	+0.1
8.2	8.1	−0.1	9.6	9.6	
4.9	4.9		3.0	2.9	−.1
6.8	6.8		6.5	6.5	
8.2	8.3	+.1	9.9	9.7	−.2
2.9	2.9		3.0	2.8	−.2
6.5	6.5		6.5	6.3	−.2
9.7	9.6	−.1	9.7	9.6	−.1
2.9	2.9		3.0	2.9	−.1
6.4	6.3	−.1	6.5	6.4	−.1
9.4	9.5	+.1	9.7	9.7	
2.9	2.9		3.0	2.9	−.1
6.2	6.4	+.2	6.5	6.4	−.1
9.6	9.5	−.1	9.6	9.6	
2.8	2.9	+.1	3.0	2.9	−.1
6.3	6.3		6.5	6.4	−.1
9.6	9.6		9.8	9.7	−.1
2.9	2.9		3.1	3.0	−.1
6.2	6.2		6.6	6.4	−.2
9.4	9.3	−.1	9.7	9.7	

SUMMARY

A method for determining the percentage of cement in soil-cement mixtures is described. Data are presented giving the results of the determination of percentage of cement in soil-cement mixtures by this method and by the method recommended by Subcommittee No. 2 of the Project Committee on "Stabilized Roads" of the Highway Research Board as a suitable method of test. In nearly half the samples the percentages of cement found by the two methods are identical. In the remaining samples, the variation is not greater than 0.2 percent. By eliminating the double precipitation of iron, aluminum, and other ions this method offers a saving in time without sacrifice of accuracy.

U. S. GOVERNMENT PRINTING OFFICE: 1944

PUBLICATIONS of the PUBLIC ROADS ADMINISTRATION

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.
Report of the Chief of the Bureau of Public Roads, 1932. 5 cents.
Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.
Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.
Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.
Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.
Report of the Chief of the Bureau of Public Roads, 1937. 10 cents.
Report of the Chief of the Bureau of Public Roads, 1938. 10 cents.
Report of the Chief of the Bureau of Public Roads, 1939. 10 cents.
Work of the Public Roads Administration, 1940, 10 cents.
Work of the Public Roads Administration, 1941, 15 cents.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.
Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.
Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.
Part 4 . . . Official Inspection of Vehicles. 10 cents.
Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.
Part 6 . . . The Accident-Prone Driver. 10 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.
No. 191MP. . Roadside Improvement. 10 cents.
No. 272MP. . Construction of Private Driveways. 10 cents.
No. 279MP. . Bibliography on Highway Lighting. 5 cents.
Highway Accidents. 10 cents.
The Taxation of Motor Vehicles in 1932. 35 cents.
Guides to Traffic Safety. 10 cents.
An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.
Highway Bond Calculations. 10 cents.
Transition Curves for Highways. 60 cents.
Highways of History. 25 cents.
Specifications for Construction of Roads and Bridges in National Forests and National Parks. 1 dollar.
Public Land Acquisition for Highway Purposes. 10 cents.
Tire Wear and Tire Failures on Various Road Surfaces. 10 cents.
Public Control of Highway Access and Roadside Development.

DEPARTMENT BULLETINS

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.
No. 1486D . . Highway Bridge Location. 15 cents.

TECHNICAL BULLETINS

No. 265T. . . Electrical Equipment on Movable Bridges. 35 cents.

Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

MISCELLANEOUS PUBLICATIONS

No. 296MP. . Bibliography on Highway Safety.
House Document No. 272 . . . Toll Roads and Free Roads.
Indexes to PUBLIC ROADS, volumes 6, 7, 11, 12, 15, and 17–22, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

REPORTS IN COOPERATION WITH UNIVERSITY OF ILLINOIS

No. 303. . . Solutions for Certain Rectangular Slabs Continuous Over Flexible Support.
No. 304. . . A Distribution Procedure for the Analysis of Slabs Continuous Over Flexible Beams.
No. 313. . . Tests of Plaster-Model Slabs Subjected to Concentrated Loads.
No. 314. . . Tests of Reinforced Concrete Slabs Subjected to Concentrated Loads.
No. 315. . . Moments in Simple Span Bridge Slabs With Stiffened Edges.
No. 336. . . Moments in I-Beam Bridges.
No. 345. . . Ultimate Strength of Reinforced Concrete Beams as Related to the Plasticity Ratio of Concrete.
No. 346. . . Highway Slab-Bridges with Curbs: Laboratory Tests and Proposed Design Method.

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.
Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.
Act III.—Uniform Motor Vehicle Civil Liability Act.
Act IV.—Uniform Motor Vehicle Safety Responsibility Act.
Act V.—Uniform Act Regulating Traffic on Highways.
Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Federal Works Bldg., Washington 25, D. C.